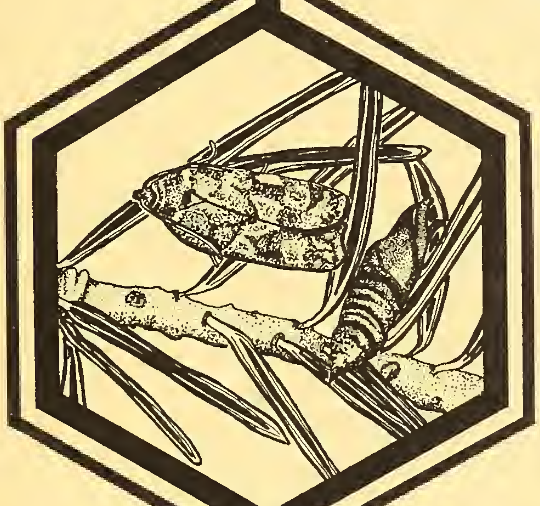
Report 79-5

#5
Aug 1979

"Data Preparation and Computer Runstream Procedures for the Douglas-fir Tussock Moth Stand-Outbreak Model".



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245 DATA PREPARATION AND COMPUTER RUNSTREAM PROCEDURES FOR THE DOUGLAS-FIR TUSSOCK MOTH STAND-OUTBREAK MODEL [1-3].

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100 John Wong[3]

ABSTRACT

A mathematical stand-outbreak model has been developed to simulate population dynamics of the Douglas-fir tussock moth, the associated defoliation, and its effect on host trees during and immediately after an outbreak. The model is available as a collection of programs on the USDA Fort Collins Computer Center UNIVAC 1100 computer. Information is provided here for use of the model on that computer. Methods for utilizing various options are also discussed.

I. INTRODUCTION

A stand-outbreak model has been developed to simulate outbreaks of the Douglas-fir tussock moth (DFTM), Orgyia pseudotsugata (McDunnough), a defoliator of Douglas-fir, Pseudotsuga menziesii var. glauca (Beissn.) Franco, and the true firs, Abies spp., in western North America. This model was developed by scientists funded by the USDA Expanded Douglas-fir Tussock Moth Research and Development Program. Details of the mathematical form of the model are given by Colbert, Overton, and White (1979a).

This model is available at the USDA Fort Collins Computer Center (FCCC) as a package of programs written in ASCII FORTRAN for the UNIVAC 1100 system. The Forest Insect and Disease Management (FI&DM) Methods Application Group (MAG) in Davis, California, has been assigned responsibility for maintaining this and other programs as a national system and to provide training and documentation for potential users.

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1 This manual was partially developed under the support of the USDA Expanded Douglas-fir Tussock Moth Research and Development Program, FS-PNW grant no. 51.

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This report is designed as a computer user's manual. It is assumed that those reading it have some familiarity with computers; those interested in the field procedures as applicable to this model should refer to Colbert and Campbell (1979).

A set of procedures is provided in this manual to illustrate how to use the model. There are three steps in the use of the stand-outbreak model:

-Decide which program options are desired.

-Prepare input files that supply information to the program(s).

-Develop an appropriate set of instructions to the computer (called a "runstream").

A discussion of the development and present structure of the stand-outbreak model follows to assist in understanding the options available and their use.

A. Model Structure

The model is organized into two levels (Fig. 1). At the top level is the stand-outbreak module (S_0), which has the least detail. At this level, spatial resolution[4] is the entire stand, and temporal resolution is annual and spans up to 10 years, including four years of insect/host interaction. In the model, an outbreak episode consists of five phases. The first three are the three years of the outbreak sequence: release, peak, and decline (Wickman et al. 1973). Because residual population densities can still be high at the end of the third phase, a post-decline fourth phase has been added to the outbreak model. To assess the effects of defoliation, the stand is followed for another six years in phase 5.

Host trees are grouped and sorted into classes. A tree class is defined by tree species; nominal[5] foliage conditions; actual foliage conditions at the beginning of the simulation; and insect density at the beginning of the simulation. Each tree class becomes a module at the second level (S_1) in the hierarchy. These modules operate independently of each other at annual resolution, except that redistribution of insects among trees within the stand is simulated by annually reducing the variance in insect density among classes. The user decides how many tree classes to use and how to partition the stand.

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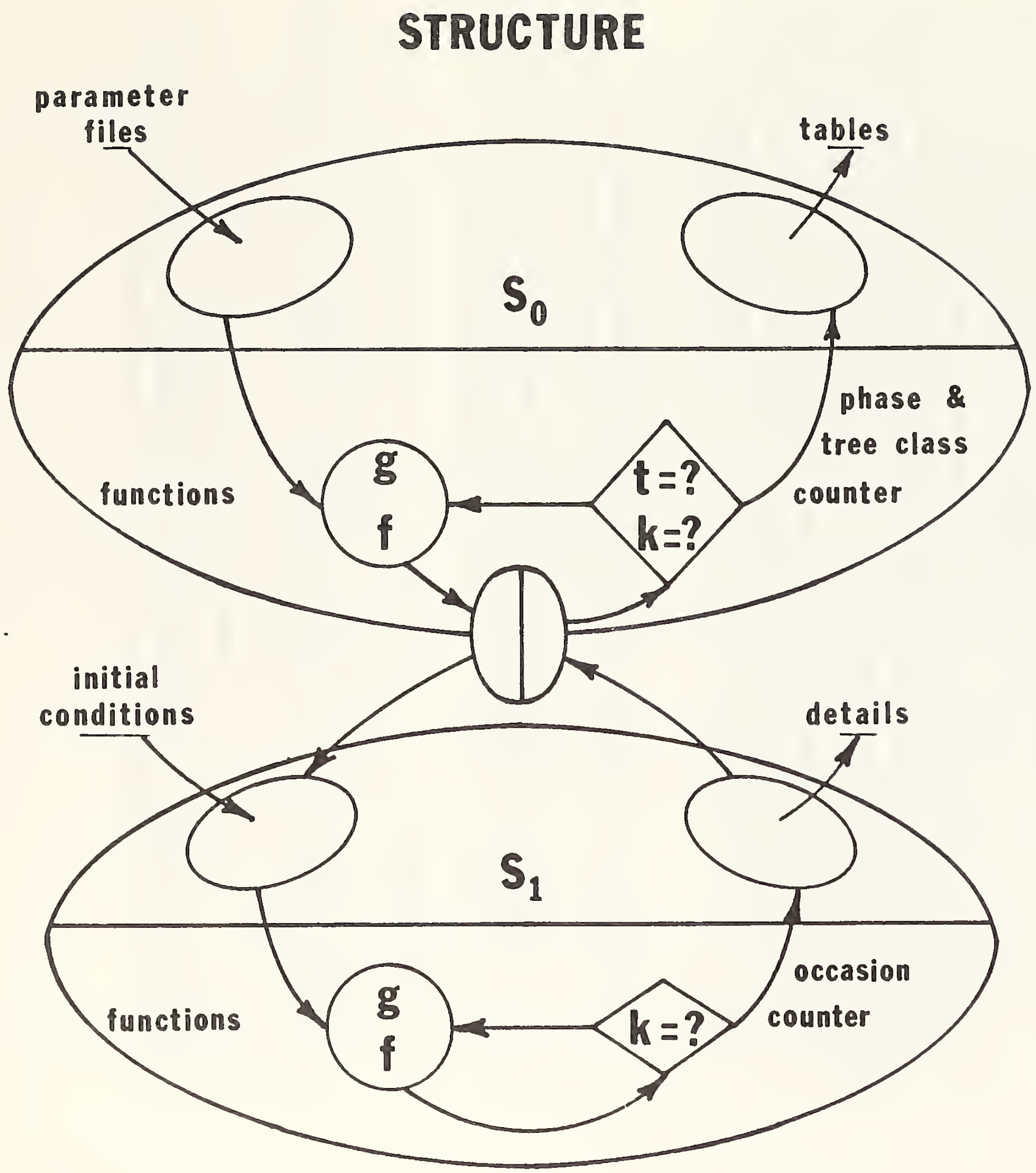
4 Resolution refers to the degree of detail that can be observed at a particular level in the model structure.

5 Throughout the manual, "nominal" refers to conditions before any defoliation.

Figure 1. Stand-outbreak model structure and resolution.



RESOLUTIONS

Spatial	Temporal
stand	outbreak
stand	phase
tree class	phase
model branch	occasion

Insect-foliage interactions, insect population dynamics, and foliage dynamics are followed through the model branch, which operates at the most detailed resolution. This is the operational portion of the tree class module. The model branch is defined as 1000 sq. in. of nominal midbole branch area along with its insect population. This module follows the insect and foliage through each year by successive projections of new and old foliage biomass, and number of insects, and larval biomass. The temporal resolution at this level is the "occasion". Each year is divided into 10 occasions. The first six of these are 10-day intervals of instar development, feeding, and mortality. Insects and foliage are followed through the rest of the year in the remaining four occasions.

B. Scope

The model was developed using data from an outbreak which occurred in the Blue Mountains of northeastern Oregon during 1971-74. The model reflects both insect life table information and observed effects of insects on host trees. Host species were Douglas-fir and grand fir, *A. grandis* (Dougl.) Lindl.. At present only limited information is available on other host species.

The model can simulate any size stand in as much detail as is available in the data base. No restriction exists on the number of tree classes that can be used. Default parameters cause the model to simulate the 1971-74 Blue Mountains outbreak, but minor parameter changes can cause it to behave like outbreaks that have occurred elsewhere providing that data are available (Colbert *et al.* 1979b). As tussock moth life table information becomes available from other areas and the model receives more use, its scope should increase. Each future outbreak will provide information that will allow the model to reproduce local eccentricities (i.e., deviations from the general pattern established for the Blue Mountains) and further validate the outbreak episode.

With the advent of early detection of outbreaks provided by pheromone traps, complete outbreak episodes can be followed. With this information and the details of effects of defoliation on other hosts such as white fir, *A. concolor* (Gord. and Glend.) Lindl., and subalpine fir, *A. lasiocarpa* (Hook.) Nutt., the model could be calibrated to simulate tussock moth outbreaks accurately wherever they occur.

C. Applications

The stand-outbreak model was originally developed to help organize ecological research. It has evolved into what is hoped will be a useful tool for biological evaluations and forecasts of population trends and their effects. Alone, it projects both a typical outbreak and the effects of defoliation in terms of subsequent growth loss, top-kill, and mortality. By exercising some of the options (Section V), it can also project the effects of potential control alternatives. The effects of variations in both natural mortality and other environmental factors can

also be explored. For example, changes in "normal" virus loads can be accommodated by altering larval disease, and pupal and overwinter mortality rates.

Long-range effects of changes in stand composition and stocking on tussock moth outbreaks can be explored when the stand-outbreak model is used in conjunction with the stand-prognosis model (Campbell and McFadden 1977). This system is operational at FCCC and is maintained by the USDA Forest Service Timber Management Staff at Fort Collins, Colorado.

II. MODEL INPUT-OUTPUT STRUCTURE

Model input is information the computer must have to complete a simulation. Four data sets or files are needed. Two of these deal with defoliation effects, one for each host species. These two files contain information utilized by the model for post-outbreak evaluations. The remaining files are structured such that initial insect densities and foliage conditions on the model branch are contained in one file while the other file contains information on insect mortalities and other model coefficients. The information contained in these two files provides the basis for describing the interaction between the insect and the host throughout the four phases of an outbreak.

All information produced through a simulation is termed model output. During a simulation three tables are produced: a summary of annual insect and foliage changes on the model branch (Table 1); defoliation of the model branch and tree and subsequent effects (Table 2); and a summary of the parameters (quantities which determine the characteristics of an outbreak) that produced the simulation (Table 3). Most details of a simulation are also available as an option (Table 4).

A. Information Needed

Four data files are required to produce a simulation. Three of these are parameter files. The fourth contains tree-class parameters and initial conditions.

The first parameter file is *PARAMETERS.[6]. Table 3 provides an example of most of the information required for this file. All control mortality rates are entered here[7].

The other two parameter files, DFTM*DFTMGF. and DFTM*DFTMDF., contain values for determining effects of defoliation on the two host species for which data are available. All parameters in the file DFTM*DFTMGF. are for determining the effects of defoliation on grand

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6 File names at FCCC always end with a period.

7 All parameters in *PARAMETERS., their default values, and a brief description of each parameter are listed in Appendix A.

fir; DFTM*DFTMDF. is for Douglas-fir (Figure 9, Appendix D). While these two files are available to the user, it is anticipated that most users will not need to modify data contained in them.

Until more complete data for the effects of tussock moth defoliation on white and subalpine fir become available, you may substitute the information available for grand fir. Existing research on white fir indicates close agreement between white and grand fir regarding the effects of tussock moth defoliation.

Limited data from subalpine fir suggest that the moth affects this species less than grand fir. The stress mortality rate for tussock moth feeding on subalpine fir is higher than for any of the other host species (Beckwith 1976, 1978). The increased insect mortality causes less defoliation from the same initial population. Hence less defoliation results in less tree mortality, top-kill, and growth loss. To date, this information has not been sufficiently quantified to justify separate parameters for this species, however.

The final set of information needed to produce a simulation contains the tree-class parameters and initial conditions. These are given by specifying nine items for each tree class (Fig. 2). This information is stored in a file named *IC..

A subset of the tree classes constructed as file *IC. can be selected to be used in a simulation. Variation in foliage and insect population data can be used to produce a set of tree classes that will describe the range of potential defoliation.

B. Information Produced

The model simulation produces three tables, the first two structured by tree class. The pages of Tables 1 and 2 are numbered 1.1, 1.2,...; 2.1. 2.2,... etc., to assist the user in cross-referencing between insects, defoliation, and the results of defoliation. Table 3 is an example of the summary of parameters from *PARAMETERS..

Table 1 is an annual resolution summary of the four outbreak phases (years). Each phase is summarized by displaying the number of insects and foliage complement at the beginning of the year, and the defoliation and number of viable eggs produced at the end of the year.

Table 2 is a defoliation summary and effects table that gives, for each tree class, the model branch defoliation for each year of the simulation and the translation of maximum branch defoliation into percent of crown totally defoliated. Crown defoliation is then used to produce expectations of direct and secondary mortality, top-kill, and growth loss to trees of each class.

Direct mortality is that which is attributable to defoliation by the tussock moth. Secondary mortality is that attributable to bark beetles and all other causes. Secondary mortality is computed as a function of

Figure 2. Intial conditions and parameters used to describe a tree class (information stored in the file *IC.).

Item No.	Description
1.	Species code: 1 for Douglas-fir, 2 for grand fir.
2.	Number of trees or trees/acre that this tree class represents. Used when redistribution of insects between tree classes is considered (Section V-D).
3.	Weight factor. Whole-tree crown-foliage weight (kg) for one tree representative of the class. Used when redistribution of insects between tree classes is considered (Section V-D).
4.	Nominal percent new foliage. The percent of total foliage biomass (needle dry weight, g/1000 sq. in.) that is all current year's growth. Nominal percentage is defined as current year's growth from midcrown samples of branches that have not been fed upon (Section V-D).
5.	Nominal total foliage biomass (needle dry weight, g/1000 sq. in.) of midcrown sample branches (Section V-D).
6.	Actual new foliage (current year's growth) biomass at the initiation of simulation (needle dry weight, g/1000 sq. in.). If some previous defoliation is assumed or has been measured, this will be less than the nominal amount from items 4 and 5 above (Section V-E).
7.	Actual old foliage biomass at the initiation of simulation (needle dry weight, g/1000 sq. in.) (Section V-E).
8.	Initial number of established first instars per model branch (1000 sq. in.) (Section V-F).
9.	Tree-class number. A reference or index number to assist the user in classification. It is used in output tables for cross-referencing (Section V-A).

Table 1. Insect and foliage densities over the life of a typical Douglas-fir tussock moth outbreak.

TABLE 1 1 INPUT-OUTPUT VARIABLE VALUES OVER THE OUTBREAK CYCLE 1501 0521

FOR THE DOUGLAS-FIR 25 000 / 75 000 TREE CLASSES WITH TOTAL FOLIAGE BIOMASS OF 200.000 GRAMS

		PHASE I						PHASE II					
		INPUTS			OUTPUTS			INPUTS			OUTPUTS		
TREE CLASS NO	NUMBER OF STEMS	VIABLE EGGS (NO)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIA-TION (%)	VIABLE EGGS LAID (NO)	REDIS-TRIBUTED EGGS (NO)	VIABLE EGGS (NO)	TOTAL FOLIAGE BIOMASS (GRAMS)	PERCENT NEW FOLIAGE (%)	DEFOLIA-TION (%)	VIABLE EGGS LAID (NO.)	REDIS-TRIBUTED EGGS (NO.)
1	000	1 000	200 000	25 000	.606	14 878	14 878	7. 439	199. 849	24. 943	4. 548	80. 812	80. 812
2	000	2 000	200 000	25 000	1. 212	29. 755	29. 755	14 878	199. 697	24. 886	9. 095	161. 623	161. 623
3	000	3 000	200 000	25. 000	1 817	44. 633	44. 633	22. 317	199. 546	24. 829	13. 643	242. 435	242. 435
4	000	4 000	200 000	25 000	2 423	59. 511	59. 511	29. 755	199. 394	24. 772	18. 191	323. 246	323. 246
5	000	5 000	200 000	25 000	3 029	74. 388	74. 388	37. 194	199. 243	24. 715	22. 738	404. 058	404. 058
6	000	6 000	200 000	25 000	3. 635	89. 266	89. 266	44. 633	199. 091	24. 658	28. 468	460. 626	460. 626
7	000	7 000	200 000	25. 000	4 240	104. 144	104. 144	52. 072	198. 940	24. 600	35. 137	497. 799	497. 799
8	000	8 000	200. 000	25. 000	4. 846	119. 021	119. 021	59. 511	198. 788	24. 543	41. 773	543. 054	543. 054
9	000	9 000	200 000	25 000	5 452	133. 899	133. 899	66. 950	198. 637	24. 485	48. 179	589. 116	589. 116
10	000	10 000	200 000	25 000	6. 058	148. 777	148. 777	74. 388	198. 486	24 428	54. 790	630. 330	630. 330
11	000	11 000	200 000	25 000	6. 664	163. 654	163. 654	81. 827	198. 334	24. 370	61. 088	675. 585	675. 585
12	000	12 000	200 000	25 000	7 269	178. 532	178. 532	89. 266	198. 183	24. 312	67. 420	717. 607	717. 607
13	000	13 000	200 000	25 000	7. 875	193. 410	193. 410	96. 705	198. 031	24. 254	73. 774	756. 396	756. 396
14	000	14 000	200 000	25 000	8. 481	208. 287	208. 287	104. 144	197. 880	24. 196	80. 140	791. 953	791. 953
15	000	15 000	200 000	25 000	9. 087	223. 165	223. 165	111. 583	197. 728	24. 138	81. 701	777. 852	777. 852
		PHASE III						PHASE IV					
1	000	32 325	198. 863	24 571	13 710	35. 253	35. 253	5. 288	196. 572	23. 692	2. 661	.948	.948
2	000	64 649	197 726	24 138	28 560	62 751	62. 751	9. 413	185. 740	23. 075	8. 817	1. 687	1. 687
3	000	96. 974	196. 589	23 699	48 015	78. 262	78. 262	11. 739	141. 966	26. 764	31. 121	2. 104	2. 104
4	000	129 298	195. 452	23 255	60. 387	82. 934	82. 934	12. 440	114. 129	30. 582	45. 165	2. 229	2. 229
5	000	161 623	194 315	22. 806	66. 115	79. 707	79. 707	11. 956	101. 240	33. 061	51. 522	2. 142	2. 142
6	000	184 250	185. 947	23. 062	75 730	83 205	83. 205	12 481	79. 608	39. 026	62. 432	2. 236	2. 236
7	000	199. 120	170. 942	24. 111	85 162	82. 319	82. 319	12. 348	58. 386	49. 172	73. 019	2. 213	2. 213
8	000	217 221	156. 010	25. 355	91. 484	75. 204	75. 204	11 281	44. 160	61. 433	79. 941	2. 021	2. 021
9	000	235 646	141 597	26. 805	100. 000	65. 212	65. 212	9 782	23. 000	100. 000	90. 253	1. 753	1. 753
10	000	252 132	126. 722	28 647	78. 406	31. 408	31 408	4 711	73. 587	41. 310	64. 051	.844	.844
11	000	270. 234	112. 553	30 855	72 327	13. 237	13 237	1. 986	87. 264	36. 577	56. 724	.356	.356
12	000	287 043	98. 306	33 716	73 115	5. 527	5 527	.829	85. 492	37. 104	57. 403	.149	.149
13	000	302 558	84 009	37 563	81. 467	5 826	5. 826	.874	66. 700	44. 428	66. 807	.157	.157
14	000	316 781	69 685	43 000	84. 890	2 397	2. 397	.360	58. 998	48. 777	70. 565	.064	.064
15	000	311 141	66. 172	44 694	86 295	2. 354	2 354	353	55. 836	50. 911	72. 146	.063	.063

Table 2. Summary of defoliation and defoliation effects, second table of information produced by the Douglas-fir tussock moth stand-outbreak model.

TABLE 2 1 OUTBREAK DEFOLIATION SUMMARY AND THE EXPECTED MORTALITY AND GROWTH REDUCTION 1501 0521

FOR THE DOUGLAS-FIR 25 000 / 75 000 TREE CLASSES WITH TOTAL FOLIAGE BIOMASS OF 200.000 GRAMS

TREE CLASS NO	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	MODEL BRANCH PERCENT DEFOLIATION BY PHASE I	II	III	IV	PERCENT OF TREE TOTALLY DEFOLIATED	PER CENT OF TREES RECEIVING: DIRECT MORTALITY	SECONDARY MORTALITY	TOP KILL	ONLY GROWTH REDUCTION
1	0	0	1 000	606	4 548	13 710	2 661	.000	.0	12.7	11.6	75.7
2	0	0	2 000	1.212	9 095	28 560	8 817	.002	.0	12.7	11.6	75.7
3	0	0	3 000	1 817	13 643	48 015	31.121	193	.0	12.7	11.6	75.7
4	0	0	4 000	2 423	18.191	60 387	45 165	3 054	.0	12.7	11.6	75.7
5	0	0	5.000	3 029	22 738	66 115	51 522	10.286	.0	12.7	11.6	75.7
6	0	0	6.000	3 635	28 468	75 730	62.432	49 718	.9	10.1	41.6	47.4
7	0	0	7 000	4 240	35.137	85 162	73.019	87.991	17.3	20.0	28.9	33.8
8	0	0	8 000	4 846	41.773	91 464	79.941	95.533	47.7	11.4	20.1	20.8
9	0	0	9.000	5.452	48.179	100.000	90.253	98.675	47.7	11.4	20.1	20.8
10	0	0	10.000	6.058	54.790	78.406	64.051	64.061	.9	10.1	41.6	47.4
11	0	0	11.000	6.664	61.088	72.327	56.724	31.654	.0	13.6	20.8	65.6
12	0	0	12.000	7.269	67 420	73 115	57.403	35.582	.9	10.1	41.6	47.4
13	0	.0	13.000	7 875	73.774	81.467	66.807	77 502	2.8	10.8	48.2	38.3
14	0	0	14 000	8.481	80 140	84 890	70.565	87 417	17.3	20.0	28.9	33.8
15	0	0	15.000	9 087	81.701	86.295	72 146	90.105	17.3	20.0	28.9	33.8

TREE CLASS NO	NUMBER OF TREES	WEIGHT FACTOR PER TREE	INITIAL VIABLE EGGS PHASE I	PER CENT OF TREES BY PERCENT REDUCTION IN CROWN HEIGHT 0 0	5.0	17.5	37.5	70.0	GROWTH IN SURVIVING TREES WITH NO TOP KILL PERCENT OF NOMINAL DIAMETER	HEIGHT	DIAMETER GROWTH IN TREES WITH TOP KILL PERCENT OF NOMINAL
1	0	.0	1.00	6.9	4.6	.0	.0	.0	89.20	89.20	89.20
2	0	0	2 00	6 9	4.6	.0	.0	.0	89.20	89.20	89.20
3	0	.0	3.00	6.9	4.6	.0	.0	.0	89.20	89.20	89.20
4	0	.0	4 00	6 9	4.6	.0	.0	.0	89.20	89 20	89.20
5	0	.0	5 00	6.9	4.6	.0	.0	.0	89.20	89.20	89.20
6	0	.0	6 00	18 0	21.3	.0	2.4	.0	75.40	75 40	75.40
7	0	.0	7.00	13 8	6.0	.0	7.8	1.4	69 80	69.80	69.80
8	0	0	8.00	15 3	3 8	.0	0	.9	57 20	57 20	57.20
9	0	.0	9.00	15.3	3 8	.0	0	.9	57.20	57.20	57.20
10	0	.0	10.00	18 0	21.3	.0	2.4	.0	75.40	75.40	75.40
11	0	.0	11 00	13 6	7 0	.0	.0	.3	80.10	80.10	80.10
12	0	.0	12.00	18.0	21 3	.0	2.4	.0	75.40	75.40	75.40
13	0	.0	13.00	23 8	16.1	.0	8 4	.0	72.70	72.70	72.70
14	.0	.0	14 00	13 8	6 0	.0	7.8	1.4	69.80	69.80	69.80
15	0	0	15.00	13 8	6 0	.0	7.8	1.4	69.80	69.80	69.80

Table 3. Parameters used to simulate Douglas-fir tussock moth outbreaks; third table of information produced by the model.

TABLE 3 PARAMETERS FOR AN OUTBREAK MORTALITY RATES, AND OTHERS 1459 0521

BY HOST, STAND, PHASE, OR INSTAR

DESCRIPTION	PHASE	SPECIES	INSTAR 1	2	3	4	5	6	OCCASION PUPAE/ADULT	OVERWINTER	EGG MASS SIZE
DAILY MORTALITY SOURCE			DAILY MORTALITY RATE						LIFE STAGE MORTALITY RATES		
BACKGROUND	I, II, III, IV	DF, GF	.020	.020	.020	.020	.020	.020			
DISEASE	I	DF, GF	.000	.000	.000	.000	.000	.000			
	II	DF, GF	.000	.000	.000	.000	.001	.001			
	III	DF, GF	.002	.003	.006	.013	.035	.028			
	IV	DF, GF	.025	.028	.031	.034	.035	.035			
PARASITE/PREDATOR	I	DF, GF	.000	.000	.000	.000	.000	.000			
	II	DF, GF	.000	.000	.000	.000	.001	.001			
	III	DF, GF	.001	.002	.003	.010	.016	.042			
	IV	DF, GF	.005	.006	.007	.021	.033	.056			
STRESS	I, II, III, IV	DF	.920	.600	.070	.000	.000	.000			
	I, II, III, IV	GF	.950	.700	.100	.020	.000	.000			
CONTROL	I	DF, GF	.000	.000	.000	.000	.000	.000	.000	.000	
	II	GF, DF	.000	.000	.000	.000	.000	.000	.000	.000	
	III	GF, DF	.000	.000	.000	.000	.000	.000	.000	.000	
	IV	GF, DF	.000	.000	.000	.000	.000	.000	.000	.000	
LIFE STAGE MORTALITY	I	DF, GF							.500	.500	
	II	DF, GF							.620	.600	
	III	DF, GF							.750	.850	
	IV	DF, GF							.800	.900	
NOMINAL EGG MASS SIZE	I	DF, GF									200.0
	II	DF, GF									200.0
	III	DF, GF									150.0
	IV	DF, GF									150.0
DESTRUCTION/CONSUMPTION RATIOS											
NEW FOLIAGE	I, II, III	DF, GF	5.400	6.250	6.250	2.710	2.270	2.200			
OLD FOLIAGE	I, II, III	DF, GF	5.400	6.250	6.250	3.690	3.290	3.200			
MEAN INDIVIDUAL LARVAL GROWTH RATE	I, II, III	DF, GF	.1147	.1147	.1147	.0886	.0625	.0625			

REDISTRIBUTION COEFFICIENT FOR THE OUTBREAK: .000

PHASE SPECIFIC MEAN EGG DENSITY BY PHASE: I= .000 II= .000 III= .000 IV= .000

the expected proportion of trees in each of the five top-kill classes subsequent to direct mortality. Once secondary mortality has been removed, growth loss is computed for the remaining trees. Currently in the model height-growth loss is proportional to radial-growth loss.

Table 3 contains a summary of important parameters used to produce Tables 1 and 2 discussed above. They are the insect natural and control mortality rates for each life stage and year of the simulation; nominal (maximum) fecundity; mean daily individual larval growth rate; the destruction/consumption ratio (used to determine the amount of foliage actually destroyed as the insects consume foliage); and the redistribution coefficient and mean fall egg densities over the stand for each phase. The full set of parameters used in a simulation are given in Section III.

C. Model Details

During a simulation, four variables (new and old foliage biomass, number of insects, and mean larval biomass) are followed through 10 occasions or time intervals. Values of these variables at points between these occasions can be obtained by an optional sorting program. This program produces the additional table (Table 4) of requested details of a simulation. One variable, mean larval biomass, was not presented in the earlier tables. This variable follows a preset trajectory (course) according to the growth rates given in Table 3, as long as foliage is available to maintain growth.

Figure 3 describes the occasion structure and times at which detailed information is available for Table 4. Occasion as used here refers to an interval of time during which specific prescribed activities take place. By stipulation of the variable of interest and the time during the simulated year of interest, the Table 4 program will sort through the simulation details and assemble the requested information for each tree class.

III. INPUT FILE FORMATS

A. Parameter File

The parameter file is read from the file named *PARAMETERS. in the following formats: first record (1I2, 1I4, 20I3); remaining 24 records (6F12.7). Figure 4 gives default values for this file in these formats. The information contained in this figure was utilized to generate Tables 1, 2, and 3 discussed earlier. Appendix A gives location, value, and descriptions for each parameter.

B. Host Effects Files

The two host effects files are DFTM*DFTMDF. and DFTM*DFTMGF. for Douglas-fir and grand fir respectively. The two standard format default files are given in Appendix D.

Table 4. Sample output of an optionally available model details of a simulation (selected pages).

TABLE 4. DETAIL RUN INFORMATION, PAGE 2

	NEW FOLIAGE BIOMASS START SIXTH INSTAR				NEW FOLIAGE BIOMASS END LARVAL STAGE-START PUPAL				NEW FOLIAGE (BUD) POTENTIAL FOR THE FOLLOWING YEAR			
SPECIES DOUGLAS	%NEW FOLIAGE 25.00		TOTAL FOL 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS
TREE CLASS	I	II	III	IV	I	II	III	IV	I	II	III	IV
1	49.007	42.480	24.612	44.755	48.788	40.905	22.579	44.677	49.849	48.863	46.572	49.335
2	48.013	34.959	.000	39.625	47.577	31.809	.000	39.487	49.697	47.726	42.860	47.796
3	47.020	27.439	.000	33.961	46.365	22.714	.000	33.789	49.546	46.589	37.996	42.220
4	46.026	19.919	.000	30.627	45.154	13.618	.000	30.445	49.394	45.452	34.903	38.709
5	45.033	12.398	.000	29.362	43.942	4.523	.000	29.186	49.243	44.315	33.471	37.119
6	44.039	4.878	.000	26.778	42.731	.000	.000	26.595	49.091	42.883	31.068	34.392
7	43.046	.000	.000	24.465	41.519	.000	.000	24.284	48.940	41.216	28.710	31.745
8	42.052	.000	.000	23.252	40.308	.000	.000	23.086	48.788	39.557	27.129	30.015
9	41.059	.000	.000	19.638	39.096	.000	.000	19.494	48.637	37.955	23.000	27.437
10.	40.066	.000	.000	28.779	37.884	.000	.000	28.710	48.486	36.302	30.399	33.987
11	39.072	.000	.000	31.236	36.673	.000	.000	31.207	48.334	34.728	31.918	35.819
12.	38.079	.000	.000	31.436	35.461	.000	.000	31.424	48.183	33.145	31.721	35.649
13.	37.085	.000	.000	29.333	34.250	.000	.000	29.320	48.031	31.557	29.633	33.298
14	36.092	.000	.000	28.654	33.038	.000	.000	28.649	47.880	29.965	28.778	32.359
15.	35.098	.000	.000	28.305	31.827	.000	.000	28.300	47.728	29.575	28.426	31.964

	OLD FOLIAGE BIOMASS INITIATION OF YEAR				OLD FOLIAGE BIOMASS START FIRST INSTAR				OLD FOLIAGE BIOMASS START SECOND INSTAR			
SPECIES DOUGLAS	%NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS
TREE CLASS	I	II	III	IV	I	II	III	IV	I	II	III	IV
1	150.000	150.000	150.000	150.000	150.000	150.000	150.000	150.000	150.000	150.000	150.000	150.000
2	150.000	150.000	150.000	142.880	150.000	150.000	150.000	142.880	150.000	150.000	150.000	142.880
3	150.000	150.000	150.000	103.970	150.000	150.000	150.000	103.970	150.000	150.000	150.000	103.970
4.	150.000	150.000	150.000	79.225	150.000	150.000	150.000	79.225	150.000	150.000	150.000	79.225
5	150.000	150.000	150.000	67.769	150.000	150.000	150.000	67.769	150.000	150.000	150.000	67.769
6	150.000	150.000	143.064	48.541	150.000	150.000	143.064	48.541	150.000	150.000	143.064	48.541
7	150.000	150.000	129.726	29.677	150.000	150.000	129.726	29.677	150.000	150.000	129.726	29.677
8	150.000	150.000	116.453	17.031	150.000	150.000	116.453	17.031	150.000	150.000	116.453	17.031
9.	150.000	150.000	103.642	.000	150.000	150.000	103.642	.000	150.000	150.000	103.642	.000
10.	150.000	150.000	90.420	43.188	150.000	150.000	90.420	43.188	150.000	150.000	90.420	43.188
11.	150.000	150.000	77.825	55.346	150.000	150.000	77.825	55.346	150.000	150.000	77.825	55.346
12.	150.000	150.000	65.161	53.771	150.000	150.000	65.161	53.771	150.000	150.000	65.161	53.771
13	150.000	150.000	52.452	37.067	150.000	150.000	52.452	37.067	150.000	150.000	52.452	37.067
14.	150.000	150.000	39.720	30.220	150.000	150.000	39.720	30.220	150.000	150.000	39.720	30.220
15	150.000	150.000	36.597	27.409	150.000	150.000	36.597	27.409	150.000	150.000	36.597	27.409

Table 4 cont'd.

TABLE 4 DETAIL RUN INFORMATION. PAGE 4

	NUMBER OF INSECTS INITIATION OF YEAR				NUMBER OF INSECTS START FIRST INSTAR				NUMBER OF INSECTS START SECOND INSTAR			
SPECIES DOUGLAS	%NEW FOLIAGE 25.00		TOTAL FOL 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS
TREE CLASS	I	II	III	IV	I	II	III	IV	I	II	III	IV
1	1.000	7.439	32.325	5.288	1.000	7.439	32.325	5.288	.817	6.078	25.630	3.190
2	2.000	14.878	64.649	9.413	2.000	14.878	64.649	9.413	1.634	12.156	51.261	5.679
3	3.000	22.317	96.974	11.739	3.000	22.317	96.974	11.739	2.451	18.234	76.891	7.082
4	4.000	29.755	129.298	12.440	4.000	29.755	129.298	12.440	3.268	24.312	102.521	7.505
5	5.000	37.194	161.623	11.956	5.000	37.194	161.623	11.956	4.085	30.390	128.152	7.213
6	6.000	44.633	184.250	12.481	6.000	44.633	184.250	12.481	4.902	36.468	146.093	7.530
7	7.000	52.072	199.120	12.348	7.000	52.072	199.120	12.348	5.720	42.547	157.883	7.450
8	8.000	59.511	217.221	11.281	8.000	59.511	217.221	11.281	6.537	48.625	172.236	6.806
9	9.000	66.950	235.646	9.782	9.000	66.950	235.646	9.782	7.354	54.703	186.845	5.901
10	10.000	74.388	252.132	4.711	10.000	74.388	252.132	4.711	8.171	60.781	199.917	2.842
11	11.000	81.827	270.234	1.986	11.000	81.827	270.234	1.986	8.988	66.859	214.270	1.198
12	12.000	89.266	287.043	.829	12.000	89.266	287.043	.829	9.805	72.937	227.598	.500
13	13.000	96.705	302.558	.874	13.000	96.705	302.558	.874	10.622	79.015	239.900	.527
14	14.000	104.144	316.781	.360	14.000	104.144	316.781	.360	11.439	85.093	251.177	.217
15	15.000	111.583	311.141	.353	15.000	111.583	311.141	.353	12.256	91.171	246.705	.213

	NUMBER OF INSECTS START THIRD INSTAR				NUMBER OF INSECTS START FOURTH INSTAR				NUMBER OF INSECTS START FIFTH INSTAR			
SPECIES DOUGLAS	%NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL 200.000	BIOMASS	SPECIES DOUGLAS %NEW FOLIAGE 25.00		TOTAL FOL. 200.000	BIOMASS
TREE CLASS	I	II	III	IV	I	II	III	IV	I	II	III	IV
1	.668	4.966	19.919	1.848	.545	4.058	14.871	1.027	.446	3.315	9.641	.480
2	1.335	9.932	39.838	3.289	1.091	8.116	29.743	1.828	.891	6.631	19.282	.855
3	2.003	14.899	59.758	4.102	1.636	12.173	44.614	2.280	1.337	9.946	28.924	1.066
4	2.670	19.865	79.677	4.347	2.182	16.231	51.449	2.416	1.783	13.262	33.355	1.130
5	3.338	24.831	99.596	4.177	2.727	20.289	51.729	2.322	2.229	16.577	33.536	1.086
6	4.006	29.797	113.540	4.361	3.273	24.347	54.843	2.424	2.674	19.893	35.555	1.133
7	4.673	34.764	122.702	4.314	3.818	28.404	55.120	2.398	3.120	23.208	35.735	1.121
8	5.341	39.730	133.857	3.941	4.364	32.462	52.007	2.191	3.566	26.524	33.717	1.024
9	6.008	44.696	145.211	3.418	4.909	36.520	52.469	1.900	4.011	29.839	34.017	.888
10	6.676	49.662	62.148	1.646	5.455	40.578	22.456	.915	4.457	33.155	14.559	.428
11	7.344	54.629	26.644	.694	6.000	44.635	9.627	.386	4.903	36.470	6.241	.180
12	8.011	59.595	11.320	.290	6.546	48.693	4.090	.161	5.348	39.786	2.652	.075
13	8.679	64.561	11.932	.305	7.091	52.751	4.312	.170	5.794	43.101	2.795	.079
14	9.347	69.527	4.997	.126	7.637	56.809	1.806	.070	6.240	46.417	1.171	.033
15	10.014	74.493	4.908	.123	8.182	56.606	1.774	.069	6.686	46.251	1.150	.032

Table 4 cont'd.

TABLE 4 DETAIL RUN INFORMATION, PAGE 6

	MEAN LARVAL BIOMASS START THIRD INSTAR				MEAN LARVAL BIOMASS START FOURTH INSTAR				MEAN LARVAL BIOMASS START FIFTH INSTAR			
	SPECIES DOUGLAS	%NEW FOLIAGE 25.00	TOTAL FOL 200.000	BIOMASS	SPECIES DOUGLAS	%NEW FOLIAGE 25.00	TOTAL FOL 200.000	BIOMASS	SPECIES DOUGLAS	%NEW FOLIAGE 25.00	TOTAL FOL. 200.000	BIOMASS
TREE CLASS	I	II	III	IV	I	II	III	IV	I	II	III	IV
1	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
2	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
3	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
4	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
5	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
6	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
7	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
8	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
9	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
10	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
11	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
12	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
13	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
14	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916
15	1.953	1.953	1.953	1.953	6.150	6.150	6.150	6.150	14.916	14.916	14.916	14.916

	MEAN LARVAL BIOMASS START SIXTH INSTAR				MEAN LARVAL BIOMASS END LARVAL STAGE-START PUPAL				NO. DAYS ON OLD FOLIAGE DURING FIRST INSTAR			
	SPECIES DOUGLAS	%NEW FOLIAGE 25.00	TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS	%NEW FOLIAGE 25.00	TOTAL FOL. 200.000	BIOMASS	SPECIES DOUGLAS	%NEW FOLIAGE 25.00	TOTAL FOL. 200.000	BIOMASS
TREE CLASS	I	II	III	IV	I	II	III	IV	I	II	III	IV
1	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
2	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
3	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
4	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
5	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
6	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
7	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
8	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
9	27.867	27.867	27.867	27.867	52.063	52.063	48.044	52.063	.000	.000	.000	.000
10	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
11	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
12	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
13	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
14	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000
15	27.867	27.867	27.867	27.867	52.063	52.063	52.063	52.063	.000	.000	.000	.000

Figure 3. The occasion structure of one year of a simulation and the times at which detailed information is available.

Access times*	Occasion descriptions
(initiation, yr j) 0	
	bud burst, new shoot elongation, egg hatch, establishment of first instars
1	
	first instars feeding, growth, and mortality
2	
	second instars feeding, growth, and mortality
3	
	third instars feeding, growth, and mortality
4	
	fourth instars feeding, growth, and mortality
5	
	fifth instars feeding, growth, and mortality (after all feeding and growth, males pupate and are no longer explicitly modeled)
6	
	sixth instars (females only) feeding, growth, and mortality
7	
	female pupation, pupal mortality, adult emergence, and adult mortality
8	
	egg laying, aging of foliage, and new foliage potential set
9	
	overwinter mortality of eggs, shedding of old foliage, and redistribution of insects between tree classes
(initiation, yr j+1) 0	

* The value of the access time given here is one less than the occasion code for accessing the state variables (see Fig. 8) (see Section V-I).

Figure 4. Default values for *PARAMETERS. given in record image format.

```
1  15   1  15   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0   0
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0010000     .0010000
     .0020000     .0030000     .0060000     .0130000     .0350000     .0280000
     .0250000     .0280000     .0310000     .0340000     .0350000     .0350000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0010000     .0010000
     .0010000     .0020000     .0030000     .0100000     .0160000     .0420000
     .0050000     .0060000     .0070000     .0210000     .0330000     .0560000
     .5000000     .6200000     .7500000     .8000000  200.0000000  200.0000000
  150.0000000  150.0000000     .0000000     .5000000     .6000000     .8500000
     .9000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .0000000     .0000000     .0000000     .0000000     .0000000     .0000000
     .9200000     .6000000     .0700000     .0000000     .0000000     .0000000
     .9500000     .7000000     .1000000     .0200000     .0000000     .0000000
     .0200000     .0200000     .0200000     .0200000     .0200000     .0200000
    5.4000000    6.2500000    6.2500000    2.7100000    2.2700000    2.2000000
    5.4000000    6.2500000    6.2500000    3.6900000    3.2900000    3.2000000
    1.1900000     .0810000     .1000000     .1147000     .0886000     .0625000
     .1970000   52.0626531     .0200000     .0100000     .0000000     .5000000
```

The other host species can be accommodated by substituting any white or subalpine fir mortality information into a file properly formatted and used in place of either DFTM*DFTMDF. or DFTM*DFTMGF. or both. If this is to be done, then the appropriate species code in the initial condition file will make the appropriate substitutions. This will also cause the species code selection of other species-specific parameters during simulation.

C. Initial Conditions File

The initial condition file, named *IC., is read in the format (1I2, 7F9.5, 1I3). Figure 2 gives descriptions of entries of any record of this file. This file is read from logical unit 1, 4, or 7 depending upon whether the simulation starts with phase I, II, or III. An example of an initial condition file for a simulation starting with phase I and covering the range from 1 to 15 initial insects per 1000 sq. in. is given in Figure 5. Each tree class in this example is Douglas-fir. Fields 2 and 3 have zero entries for all tree class records because insect redistribution is not considered. The model branch for each tree class is assumed to have 200 g. of foliage, of which 25% is current year's growth and with no previous defoliation. This file was utilized in conjunction with the parameters file in Figure 4 to produce Tables 1, 2, and 3.

A sorting routine has been built into the model program such that whenever any one of the two nominal foliage input variables in *IC. changes values, output control is automatically directed to a new page. The user should therefore group the input records accordingly to eliminate extraneous paginations.

D. Table 4

The data needed to generate Table 4 are contained in three files: *LUN10., *LUN25., and *SPECTAB4.. Specifications of information desired (Section V-D) are put in *SPECTAB4.. Figure 6 is an example of the *SPECTAB4. file. This file was used to generate Table 4. The first record or card is in format (1I3, 1I2), and each succeeding record is in format (2I2) *LUN10. and *LUN25. are computer-generated during a simulation; *SPECTAB4. is generated by the model user.

IV. RUNSTREAM GENERATION

Figure 7 provides a description of the general process of producing input files, executing a simulation, and obtaining output.

The series of computer commands, known as "control statements", that results in execution of a simulation is called the "runsteam". At FCCC, the symbol @ is always the first (left hand) character in a control statement. This symbol must appear in column 1. This section outlines procedures for generating a runstream and the available runstream options. We assume that you will be communicating with FCCC through an interactive terminal and that FCCC has assigned you an identifier (site

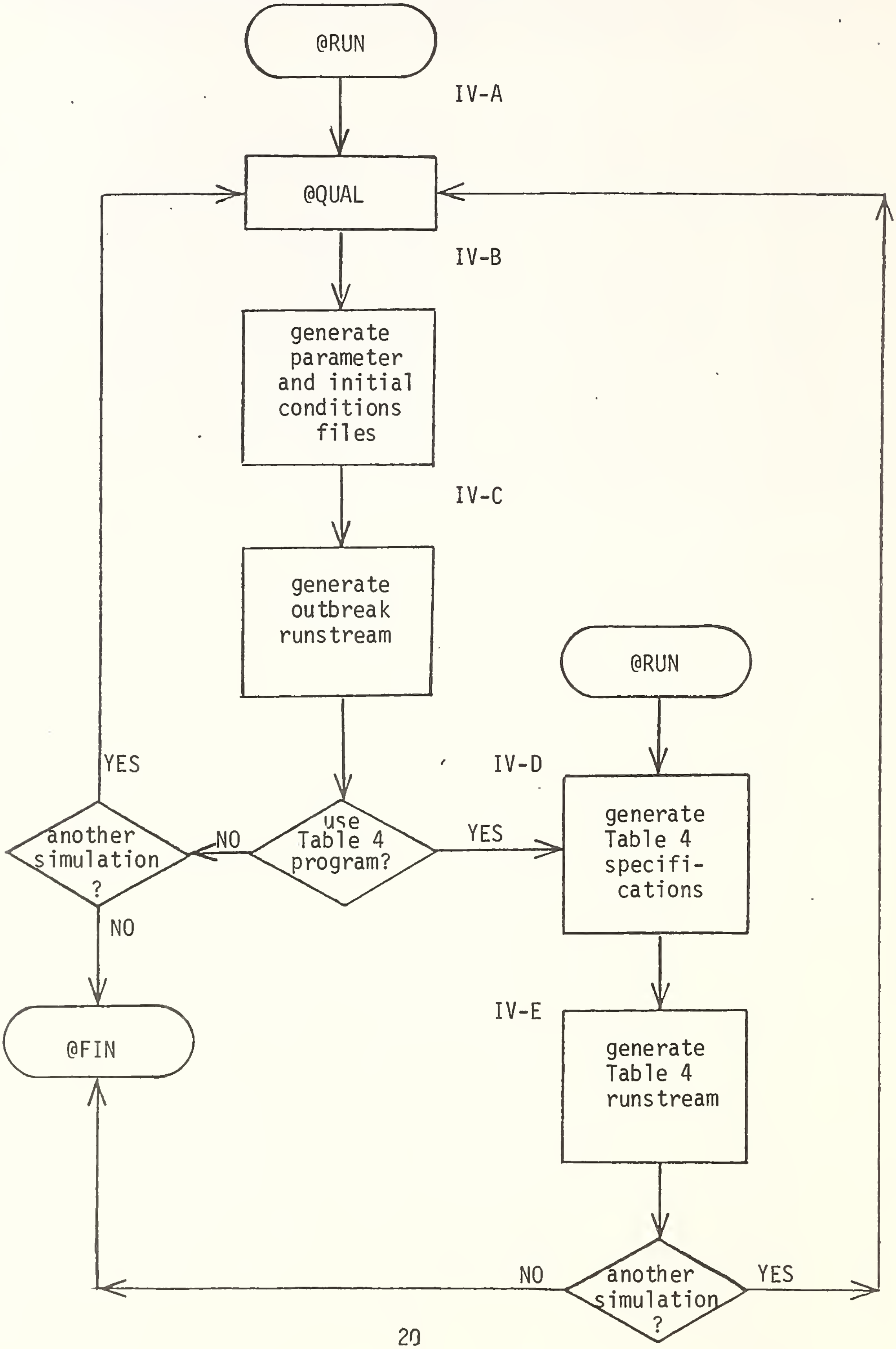
Figure 5. The initial condition file *IC. for a simulation starting with phase I initial conditions.

```
1    .00000    .00000 25.00000200.00000 50.00000150.00000  1.00000  1
1    .00000    .00000 25.00000200.00000 50.00000150.00000  2.00000  2
1    .00000    .00000 25.00000200.00000 50.00000150.00000  3.00000  3
1    .00000    .00000 25.00000200.00000 50.00000150.00000  4.00000  4
1    .00000    .00000 25.00000200.00000 50.00000150.00000  5.00000  5
1    .00000    .00000 25.00000200.00000 50.00000150.00000  6.00000  6
1    .00000    .00000 25.00000200.00000 50.00000150.00000  7.00000  7
1    .00000    .00000 25.00000200.00000 50.00000150.00000  8.00000  8
1    .00000    .00000 25.00000200.00000 50.00000150.00000  9.00000  9
1    .00000    .00000 25.00000200.00000 50.00000150.00000 10.00000 10
1    .00000    .00000 25.00000200.00000 50.00000150.00000 11.00000 11
1    .00000    .00000 25.00000200.00000 50.00000150.00000 12.00000 12
1    .00000    .00000 25.00000200.00000 50.00000150.00000 13.00000 13
1    .00000    .00000 25.00000200.00000 50.00000150.00000 14.00000 14
1    .00000    .00000 25.00000200.00000 50.00000150.00000 15.00000 15
```

Figure 6. The input specification file *SPECTAB4. that determines what is included in Table 4.

```
1547
 1 1
 2 1
 3 1
 4 1
 5 1
 6 1
 7 1
 8 1
10 1
 1 2
 2 2
 3 2
 4 2
 5 2
 6 2
 7 2
 8 2
10 2
 1 3
 2 3
 3 3
 4 3
 5 3
 6 3
 7 3
 8 3
 9 3
10 3
 2 4
 3 4
 4 4
 5 4
 6 4
 7 4
 8 4
 3 5
 4 5
 5 5
 6 5
 7 5
 8 5
 3 6
 4 6
 5 6
 6 6
 7 6
 8 6
```

Figure 7. General process of producing input files, executing a simulation, and obtaining output.



i.d.) that allows you to initiate communications. As used here, pointed brackets and the description within them should be replaced with appropriate information, e.g., <account> should be replaced with your FCCC account number.

A. Run Initiation and Identification

1. Initiate the run with the following control statement:

```
@RUN <runid>,<account>,<projectid>
```

2. Identify this run and its associated files with a "qualifier". This qualifier will allow you to identify the input and output files for each run you make. To use a qualifier, you have to know the form of a file name. File names at FCCC are structured as follows:

```
<qualifier>*<filename>.<elementname>
```

One type of file does not use element names, and is referred to only as <qualifier>*<filename>.. Output produced by the program is placed in these files, which are called systems data formatted files. Whenever a file is named (for example, by an @ASG command with the appropriate options) without a qualifier, an explicit or implied qualifier is attached to the front of the file name equal to the <projectid>. For example, if a run statement is:

```
@RUN     AB9XXX, 1234567890AB, NAME
     .
     .
     .
@ASG,UP      FILE2.                          (1)

@ASG,T       FILE17.                         (2)
     .
     .
     .
```

(1) creates a file named NAME*FILE2.. This file will be catalogued (placed in a master file directory) so it can be referenced after the run terminates. This file can be referred to simply as FILE2. in any run with <projectid> = NAME.

(2) creates a file named NAME*FILE17.. This file is not catalogued because of the "T" (temporary) option in the @ASG,T. This temporary file disappears after the run terminates. The file can be referred to simply as FILE17.. By use of the @QUAL statement, the implicit qualifier can be changed for files referred to as *<filename>.. For example:

```
@RUN <runid>,<account>,YOU

@QUAL  ME
```

```
@ASG,T  RECORDS.                                    (1)

@ASG,T   *RECORDS.                                  (2)

@ASG,UP  *STUFF.                                    (3)
```

(1) creates a temporary file named YOU*RECORDS. that can be referenced later in the same run as simply RECORDS. (or as YOU*RECORDS.).

(2) creates a temporary file named ME*RECORDS. that can be referenced later in the run as *RECORDS. (or as ME*RECORDS.). The two files RECORDS. and *RECORDS. are completely separate.

(3) creates a catalogued (permanent) file named ME*STUFF. that can be referenced later in the run or in another run as ME*STUFF. (or simply *STUFF. if the statement @QUAL ME is already in the runstream). Files always can be referenced by the whole name.

Currently available packaged runstreams for use with the stand-outbreak model (DFTM*RUNSTREAM.PRE1, DFTM*RUNSTREAM.PRE2, DFTM*RUNSTREAM.POST1, etc.) assume that you have already entered a @QUAL<i.d.> to identify the output files for this run. <i.d.> should be some word to identify the run. This word can be up to 12 characters long, using letters, numbers, and the symbols hyphen (-) and dollar sign ($). For example:

```
@QUAL     TESTRUN36-D5
```

B. <u>Parameter and Initial Condition Files</u>

Input files which are already in existence can be utilized to create new data files for another simulation. For example, assume you have previously run a simulation identified by the qualifier "RUN56" and thus have catalogued files RUN56*PARAMETERS. and RUN56*IC.. You now wish to do a simulation identified by the qualifier "RUN57", and the only changes between the input to these two runs are in the *PARAMETERS. file. Then:

```
@RUN <runid>,<account>,<projectid>

@QUAL RUN57

@ASG,UP *PARAMETERS.

@ASG,UP *IC.

@COPY RUN56*PARAMETERS.,*PARAMETERS.

@COPY RUN56*IC., *IC.

@ED,U *PARAMETERS.
```

```
        .
        .
        .
        [make changes to the *PARAMETERS.
        file using the editor processor]

        .
        .
        .
    EXIT
        .
        .
        .
```

You now have a file RUN57*IC. identical to RUN56*IC., and a file RUN57*PARAMETERS. identical to RUN56*PARAMETERS., except for the changes made above.

C. Stand-Outbreak Runstream

1. Select the appropriate packaged runstream to ready the computer for execution of the simulation. Select DFTM*RUNSTREAM.PRE1 for phase 1 initiation, DFTM*RUNSTREAM.PRE2 for phase 2 initiation, DFTM*RUNSTREAM.PRE3 for phase 3 initiation. Example:

```
@ADD DFTM*RUNSTREAM.PRE2
```

This command should result in a string of "READY" messages appearing at the terminal. When the prompt ">" appears, the computer is ready to execute the simulation with phase 2 initiation.

2. Execute the simulation:

```
@XQT DFTM*OUTBREAK.
```

After execution, the printed output from the simulation is stored in the files *15., *16., and *17. and the Table 4 input files, *LUN10. and *LUN25. have been created.

3. Select an output option. Example 1:

```
@MSG,N   <50 character address line)

@MSG,N   <50 character address line>
        .
        .
        .
@ADD DFTM*RUNSTREAM.POST1
```

The above series of commands produces a printed listing of the output files *15., *16., *17. with an address as specified in the @MSG,N commands. The files *15., *16., *17 are also deleted.

Example 2:

```
@ADD DFTM*RUNSTREAM.POST2

@SYM *15.,, <deviceid>

@SYM *16.,, <deviceid>

@SYM *17.,, <deviceid>
```

The command @ADD DFTM*RUNSTREAM.POST2 produces no listing of the output files, and it is left to you to send the output contained in *15., *16., and *17. to an appropriate device (presumably your own line printer) via the @SYM commands. Files are deleted after the @SYM unless the "U" option is specified. For example:

```
@SYM,U *15.,,  <deviceid>
```

Multiple copies of the output can be produced by inserting the number of copies between the two commas in the @SYM command. For example:

```
@SYM *<myfile>.,5,<mydevice>
```

produces five copies of *<myfile>. at <mydevice>

4. Because *LUN10. and *LUN25. are catalogued files, they will be available as input to the Table 4 program for six days after they are created. After six days, the files are purged from the system unless preserved via the @SAVE command. For example:

```
@SAVE  RUN7*LUN10., 791231

<description of contents of file to be entered by user>
```

This command will preserve the file RUN7*LUN10. until 12-31-79. The file will also carry with it the description specified. This feature is useful when trying to identify files created some time in the past.

D. Specifications for Table 4 Output

It is assumed here that you have completed a simulation and, during the run, the files <qual>*LUN10. and <qual>*LUN25. were created. The status of these files can be checked, if necesary, by use of the @STAT command. For example, @STAT *DFTM*RUNSTREAM. results in the following:

```
STATUS 2R1 R72-16 08/22/79 12:15:23

     QUAL: DFTM            ACCOUNT: 1105205205   CREATED : 06/26/79
     FILE: RUNSTREAM       STATUS : SAVED        PURGE   : 12/30/80
     CYC :    1                                  LAST REF: 06/26/79
     DESC: DFTM OUTBREAK MODEL RUNSTREAM FILES
```

If the qualifier on these two files is different from the present one, you should make a qualifier designation by inserting an @QUAL <qual> into your current runstream. Next, create the Table 4 specification file described in Sections III-D and V-G. This file must be given the name <qual>*SPECTAB4.. This file can be created by use of the editor (@ED,I) or the data command:

```
@DATA,I  <filename>.
.
.
.
   DATA GO HERE
.
.
.
@END
```

E. Table 4 Runstream

You are assumed to have three files with the same qualifier:

<qual>*LUN10.

<qual>*LUN25.

<qual>*SPECTAB4.

The first two were created by a run of the model, and the last has been created by you. A further assumption is that you are communicating with the system via an interactive (demand) terminal and have set the qualifier to match the one on these files.

Two runstreams can be used for the Table 4 program, depending on output requirements. The first, using DFTM*RUNSTREAM.TABLE4A, is for use when the output is to be routed to the FCCC line printer and mailed to you. Then, only two types of statements are necessary:

```
@MSG,N  <50 character (maximum) address for...>

@MSG,N <...mailing from FCCC to user>

@ADD DFTM*RUNSTREAM.TABLE4A
```

This runstream will first make all the necessary file assignments and linkages and will then execute the Table 4 program. After execution of the Table 4 program, its output will be disposed (via @SYM commands) to the FCCC line printer with an address given in the @MSG,N commands. Note that this will delete the output file as it prints it. If the user desires to preserve the Table 4 output file, he should use the procedure given below.

The second procedure, using DFTM*RUNSTREAM.TABLE4B, is for use when the output is to be routed directly to your device. The runstream will then be:

```
@ADD DFTM*RUNSTREAM.TABLE4B

@SYM *TABLE4.,<copies>,<your device>
```

This runstream will make all the necessary file assignments and linkages and execute the sorting program, but disposition of the program's output (contained in *TABLE4.) is left to you. Here, too, if you want to retain the output file generated (*TABLE4.), you must indicate the "U" option on your @SYM commands and use @SAVE if you wish to retain the file for more than six days.

V. OPTIONS AVAILABLE

Many options are available. Most of the relations that may be varied are assessed through changing the model parameters. Most of these values are read in at the time of execution and accessed through the four files described previously. Parameter options and access to simulation details are described and discussed in this section.

A. Years to be Simulated and Tree-Class Selection

Two options are exercised through data supplied on the first record of *PARAMETERS. (Appendix A): the phase in which the simulated outbreak begins and the number of tree classes to be included in the simulation.

1. You may start the simulation in phase I, II, or III by choosing the value 1, 2, or 3 for the first entry on the first record of the parameter file, *PARAMETERS. (Appendix A; i=1, j=1). If the simulation is to start in phase I, initial foliage complement is assumed to be the same as the nominal. Initial insect populations should be below 20 established first instars per 1000 sq. in. from midbole samples.

Starting in phase II, light defoliation may be visible, but no heavily defoliated patches should have appeared; model projections from phase I (Table 1) show only minimal deviations from nominal foliage conditions. If a simulation is to start in phase III, however, considerable previous defoliation could have occurred. "Hot spots" may have greater than 90 percent defoliation from the previous year. This is the year of heavy defoliation; collapse is beginning, survivorship is low, and the population trend from the previous year is less than 1.0.

2. The total number of tree classes desired should be put in as the second item on the first record (Appendix A; i=1, j=2) of the parameter file (*PARAMETERS.).

3. The forest unit being simulated can be stratified into tree classes. The sample data can be organized in more than one way; a tree class may represent one tree, a group of similar trees, or a collection

of similar plots. It is most efficient first to make one set of tree classes that reflect average conditions over the forest unit being studied, then subidivide by plots or groups of plots to examine variability. If an initial condition file contains more tree classes (records) than you wish to use in a particular simulation, a subset of the file can be selected by stipulating the first and last tree-class number (Figure 2, item 9) for the subsets desired. Up to 10 subsets can be selected (See Appendix A; i=1, j=3,...22).

Now, for a specific example, assume that an initial condition file contains 48 records, numbered consecutively. The first 24 records are for Douglas-fir and the last 24 for grand fir. You want to simulate using only the first 12 classes from each host species. The values 1, 12, 25, and 36 are thus entered as the third through sixth entries on record (card) number 1. All remaining entries can be left blank. The second entry on card 1 will then be 24, which is the number of tree classes to be simulated. If all 48 tree classes are desired, then the third and fourth entries on the first record should be 1 and 48, and the second entry on card 1 will be 48.

B. Insect Natural Mortality and Fecundity

As the model insect population goes through its annual cycle, population numbers are affected by mortality from natural factors and direct control. Control will be discussed in Section V-C. Natural larval mortality is divided into four sources--background, predator/parasite, disease, and stress. Background mortality is the same for each phase and is the assumed phase I net rate. Predator/parasite, disease, and stress mortalities are assumed to act independently, both of each other and of the background rate. Predator/parasite and disease rates are entered as phase- and instar-specific daily rates. Independence implies the following multiplicative rate, m_x, for a mortality factor and the associated survival, s_x:

$$s_x = 1.0 - m_x$$

Net daily survival (s) is the product of the individual survival factors ($s = s_a s_b \ldots .$). Similarly, survival (S), over the 10d instar is the product of the 10 daily survival rates

$$S = s_1 s_2 \ldots s_{10}.$$

Table 5 gives daily and instar rates from each factor, as well as the net daily rate for all factors other than stress mortality. Stress mortality operates only when the population is forced to eat old foliage. This occurs after all new foliage has been consumed.

Number of days of stress mortality must be known (see Section V-G) to incorporate this factor in net instar mortality. For example, if five days of feeding on foliage occurs in the fourth instar on grand fir during phase II:

Table 5. (a) daily larval mortality rates and net daily rate with and without stress rate included.

Source	Phase or host species	Instar 1	2	3	4	5	6
(a) Daily background	I, II, III, IV	0.02*	0.02	0.02	0.02	0.02	0.02
Predator and parasite	I	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.001	0.001
	III	0.001*	0.002	0.003	0.010	0.016	0.042
	IV	0.005	0.006	0.007	0.021	0.033	0.056
Disease	I	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.001	0.001
	III	0.002*	0.003	0.006	0.013	0.035	0.028
	IV	0.025	0.028	0.031	0.034	0.035	0.035
Food stress	Douglas-fir	0.92	0.60	0.07	0.0	0.0	0.0
	grand fir	0.95	0.70	0.10	0.02	0.0	0.0
Net daily rate without food stress	I	0.02	0.02	0.02	0.02	0.02	0.02
	II	0.02	0.02	0.02	0.02	0.027	0.027
	III	0.023*	0.025	0.029	0.042	0.069	0.087
	IV	0.049	0.053	0.057	0.073	0.086	0.107
Net daily rate including Douglas-fir stress	I	0.922	0.608	0.089	0.020	0.020	0.020
	II	0.922	0.608	0.089	0.020	0.022	0.022
	III	0.922	0.610	0.097	0.042	0.069	0.087
	IV	0.924	0.621	0.123	0.073	0.086	0.107
Net daily rate including grand fir stress	I	0.951	0.706	0.118	0.040	0.020	0.020
	II	0.951	0.706	0.118	0.040	0.022	0.022
	III	0.951	0.707	0.126	0.062	0.069	0.087
	IV	0.952	0.716	0.151	0.092	0.086	0.107

* (1.0-0.023) = (1.0-0.02)(1.0-0.001)(1.0-0.002)

Table 5. (b) instar mortality rates and the net instar rates excluding stress.

Source	Phase or host species	Instar					
		1	2	3	4	5	6
(b) Instar							
Background	I, II, III IV	0.183	0.183	0.183	0.183	0.183	0.183
Predator and parasite	I	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.010	0.010
	III	0.010	0.020	0.030	0.096	0.149	0.349
	IV	0.049	0.058	0.068	0.191	0.285	0.438
Disease	I	0.0	0.0	0.0	0.0	0.0	0.0
	II	0.0	0.0	0.0	0.0	0.010	0.010
	III	0.020	0.030	0.058	0.123	0.300	0.247
	IV	0.224	0.247	0.270	0.292	0.300	0.300
Food stress	Douglas-fir	$1-10^{-11}$	$1-10^{-4}$	0.516	0.0	0.0	0.0
	grand fir	$1-10^{-13}$	$1-10^{-5}$	0.651	0.183	0.0	0.0
Net instar rate excluding stress mortality	I	0.183	0.183	0.183	0.183	0.183	0.183
	II	0.183	0.183	0.183	0.183	0.199	0.199
	III	0.207	0.223	0.253	0.352	0.513	0.600
	IV	0.397	0.421	0.444	0.532	0.591	0.678

$$S_{4net} = S_4\ (1.0\text{-}0.02)^5$$
$$= (0.817)\ (0.98)^5$$
$$= (0.817)\ (0.904)$$
$$= (0.739)$$

Here S_4 is the phase II, fourth-instar survival, excluding stress. Thus 73.9 percent of the number starting the fourth instar will finish it (mortality of 26.1 percent).

Suppose now that you are interested in the rate of survival (or mortality) associated with disease for the fourth instar of phase III. Because daily disease-related mortality rate is 0.013 (Table 5a), the (10d) instar survival rate is $(1.0\text{-}0.013)^{10} = 0.987^{10} = 0.877$, and the (10d) instar mortality rate is 1.0-0.877 = 0.123. To alter the given rate, and with data to support an instar mortality rate of 0.214 (for example, 21.4 percent of a rearing sample dies of disease during the fourth instar), the daily rate would be obtained for entry into *PARAMETERS. as follows:

$$S_{instar} = 1.0\text{-}0.214$$
$$S_{instar} = 0.786 = S_{10d}$$
$$S_{daily} = 0.786^{\frac{1}{10}} = 0.976 = 1.0\text{-}0.024,$$

hence the daily survival rate to enter in replacement of 0.013 in *PARAMETERS. is 0.024.

Occasion mortalities are assumed to operate similarly. Only one (natural) rate is provided for each occasion. For example, all natural mortality factors affecting pupae in phase II are assumed to total 62 percent (value 0.62 for i=10, j=2 in Appendix A). If pupal mortality is believed to be different during phase II for some stand (area) being simulated, the second entry on the tenth record of *PARAMETERS. (Appendix A; i=10, j=2) can be replaced with the new value.

Nominal egg-mass size is the number of viable eggs produced by an adult female that has fed for the full larval interval on new foliage. This number is reduced by one percent for each day of feeding on old foliage and further reduced if the model branch is totally defoliated. The assumed nominal egg mass sizes can be replaced by changing the last two entries of record 10 (Appendix A; i=10, j=5,6) or the first two on record 11 (Appendix A; i=11, j=1,2).

C. Insect Control Mortality

To simulate direct control, first decide the phase being controlled, the time over which control is to operate, and survival for the affected stages. Assume, for instance, that previously accumulated data on a

particular pesticide suggest efficacy of 97.4 percent. The population is in the second year of visible (some heavily) defoliation. Samples, taken pre- and post-spray, and a subsample indicate that about half the population was third and half fourth instars before spray, and half fourth and half fifth after spray. A daily control mortality rate is sought that will give 97.4 percent total mortality during the fourth instar of phase III. Because fourth-instar natural mortality parameters are 0.020, 0.013, 0.010 (Table 5):

$$S_{4th\ instar} = \prod_{j=1}^{10} s_{d_j}$$

$$= (s_{d_j})^{10}$$

$$S_{4th\ instar} = (1.0-0.020)^{10}(1.0-0.013)^{10}(1.0-0.010)^{10} \cdot (1.0-m_{c_4})^{10}$$

And from the efficacy data: $S_{4th\ instar} = (1.0-0.974) = 0.026$, so that:

$$0.026 = (0.980)^{10}(0.987)^{10}(0.990)^{10}(S_{c_4})^{10}$$

$$0.026 = (0.817)\ (0.877)\ (0.904)(s_{c_4})^{10}$$

$$0.026 = (0.648)(s_{c_4})^{10}$$

$$(s_{c_4})^{10} = \frac{0.026}{0.648} = 0.040$$

$$(s_{c_4}) = (0.040)^{\frac{1}{10}} = 0.775$$

Thus the mortality parameter for 97.4 percent control in the fourth instar of phase III is $m_{c_4} = 1.0-0.725 = 0.275$, or 27.5 percent of the daily mortality is assumed to be a direct result of the pesticide.

If control acts over a longer period, you must decide what fraction of the control mortality should be included in each instar over which the control is assumed to act. For short-lived chemical agents, you may want to slow control in earlier instar(s) by assigning the highest rate to the next instar after the simulated application. With bacterial or viral control, the disease will spread--and the rate might increase in

later instars (Stelzer et al. 1975, Stelzer et al. 1977). Daily rates of mortality assigned to each instar should reflect existing data on the efficacy of the chemical or microbial being modeled.

If, in the above example, the 97.4 percent efficacy was assumed to operate over the third and fourth instars, then:

$$(1.0-0.974) = 0.026 = S_3S_4 = \prod_{j=1}^{10} s_{d_j} \cdot \prod_{j=1}^{10} s_{d_j}$$

$$=(1.0-0.020)^{10}(1.0-0.006)^{10}(1.0-0.003)^{10}(1-m_{c_3})^{10}$$

$$\cdot(1.0-0.20)^{10}(1.0-0.013)^{10}(1.0-0.010)^{10}(1-m_{c_4})^{10}$$

$$= (0.817)(0.942)(0.970)\ (1-m_{c_3})^{10}$$

$$\cdot(0.817)(0.877)(0.904)\ (1-m_{c_4})^{10}$$

$$0.026 = (0.4837)(1-m_{c_3})^{10}(1-m_{c_4})^{10}$$

$$(1-m_{c_3})(1-m_{c_4}) = (0.0537)^{\frac{1}{10}} = 0.746.$$

When defoliation removes all new foliage before the end of the period for which control parameters are to be altered, stress mortality should also be included in the calculations.

To include the effects of control on pupal/adult or overwinter mortality, the same multiplicative rule is used:

$$1-m_{total} = (1-m_{natural})(1-m_{control}).$$

For example, if the data indicate pupal/adult mortality of 78 percent as a result of phase II microbial control, and phase II naturally occurring pupal mortality is 0.620 (Table 3):

$$(1.0-0.780) = (1.0-0.620)\ (1-m_c),$$

solving for m_c gives

$$m_c = 0.421.$$

The same rule is used for combining natural overwinter mortality and control-induced overwinter mortality.

D. Foliage Nominal Conditions

Nominal whole-crown dry weight is used along with the number of trees in computing stand mean insect density for redistribution. If you want mean density of insects per unit area, then crown weights and stocking information must be provided. These are not necessary if redistribution is not considered; then, the second and third entries on each tree class (Figure 2) should be left blank. If crown weights are needed, then whole-crown foliage weights can be used; they are provided by the following regression equations (Brown 1978):

d: diameter at breast height, inches

w: foliage dry weight, pounds

Dominant/codominant:

grand fir:

$$w = \frac{\exp(1.3094 + 1.6076 \ln(d))}{1.592 + 0.059d} \text{ for } 1<d<36$$

$$w = 0.286 \exp(1.3094 + 1.6076 \ln(d)) \text{ for } 36<d<40.$$

Douglas-fir:

$$w = 0.484 \exp(1.1368 + 1.5819 \ln(d) - 0.0210d) \text{ for } 1<d<17$$

$$w = (0.4955d^2 - 10.04) \exp(-0.0210d) \text{ for } 17<d<34$$

Intermediate/suppressed:

grand fir $\quad w = 1.5747 \exp(1.6156 \ln(d) - 0.0544d),\ 1<d<12.$

Douglas-fir $\quad w = 0.5977 \exp(1.862 \ln(d) - 0.0552d),\ 1<d<11.$

The Brown publication also contains foliage information for subalpine fir. Because it uses only data from the northern Rockies, it does not contain any information for white fir or species in other geographic areas.

Nominal foliage complements for the model branch have been derived from five stands each from Arizona, New Mexico, and the northern Rockies (Idaho and Montana), as well as 10 stands from California (Table 6). Complete statistics on nominal foliage complements for Oregon and Washington have not been fully developed.

Behavior of the model has been investigated by developing an array of initial conditions that covers the range of the Douglas-fir and grand fir data and the range of phase I initial insect densities (Mason 1978; Hatch and Mika 1978). From this array, input-output tables have been

Table 6. The means and standard means for biomass and % new foliage for the model branch by geographic regions (data entries 4 and 5 for the initial condition file, Fig. 2) (from Hatch and Mika 1978).

Host species	National Forest (State)	Mean biomass	S.E.	(n)*	Mean % new	S.E.
Douglas-fir	Clearwater (ID)	219.2	12.55	(19)	27.3	1.39
	Flathead (MT)**	280.3	15.83	(20)	40.4	4.25
	Coeur d'Alene (ID)	221.9	16.54	(10)	26.6	2.13
	Santa Fe (NM)***	221.9	7.67	(50)	--	--
	Tonto (AZ)	175.5	7.18	(50)	21.4	0.983
Grand fir	Clearwater (ID)	235.7	15.21	(20)	32.4	1.58
	Coeur d'Alene (ID)	209.8	16.76	(10)	40.9	1.08
White fir	Eldorado (CA)	301.9	15.77	(30)	19.9	1.37
	Modoc (CA)	395.9	12.39	(50)	19.8	1.24
	Santa Fe (NM)***	303.1	15.87	(40)	--	--
	Stanislaus (CA)	208.2	11.63	(20)	26.4	2.00
	Tonto (AZ)	230.9	7.21	(50)	23.2	0.945

* n: The number of samples. A sample consisted of three 18-inch branches, one outer and two inner, from the midbole of a tree 60 feet or less in total height.

** Previous defoliation of portions of some of these samples may account for the high percent new foliage.

*** Limited current year's (1977) foliage was observed when samples were taken. This may also bias the total foliage biomass for this area.

produced and can be made available for user reference. These tables use all the standard default values given in Appendix A.

E. Previous Defoliation: Estimating Initial Foliage Conditions

The normal procedure for using the model has been to simulate the full four-year episode, and assume an initial foliage complement equal to the nominal. When a simulation is to start in a later phase, the user must locate both appropriate nominal foliage conditions and initial insect densities for earlier years that will match collected data[8]. From this, either back up initial conditions to phase I or use the initial foliage the model has given for the year the simulation is to begin.

If changes are made in the file that would affect model behavior before the point where an accurate simulation is desired, the above procedure will no longer apply. The user should then make an initial set of simulations to assess the effects of changes in the parameter file and choose the range of nominal foliage conditions and phase I insect densities desired.

F. Insect Population Estimates and Model Initial Insect Densities

To determine the initial insect density that will give a specific density at an intermediate point within any one year, the accumulated mortality associated with the given period must be used and the derived equation solved. For example, if the data give an average of 52 third instars/1000 sq. in. in phase III and from the age distribution of the sample, this number is assumed to correspond to the midpoint of the third instar, then

$$52 = N_{initial}\ S_1 S_2 s_{31} s_{32} s_{33} s_{34} s_{35},$$

where

$N_{initial}$: initial numbers of insects (eggs),

S_1: survival for first instars,

S_2: survival for second instars,

s_{31}-s_{35}: the daily survival for days 1-5 of the third instar

From Table 5, $S_1 = 0.793$, $S_2 = 0.777$, and $s_{31} = \ldots = s_{35} = 0.9712$. Thus the initial density that will result in 52 larvae after five days of the third instar is given by:

---

8 A set of behavior tables has been developed and is available through the Methods Application Group.

$$N_{initial} = \frac{52}{(0.793)\ (0.777)\ (0.9712)^5}$$

$$= \frac{52}{(0.793)\ (0.777)\ (0.864)} = 97.67$$

So 98 established first instars (initial eggs) will give 52 insects half way through the third instar. We have assumed no stress mortality here. If stress mortalty need be incorporated, the instar rate can be read from Table 5, or stress mortality can be obtained from the parameter file (Appendix A), and the survivorship equations as described in V-B and V-C above can be used.

G. Details of a Simulation

Table 4 may be produced after a simulation. Using two data files produced during a simulation (*LUN10. and *LUN25.) and a specifications file you supply (*SPECTAB4.), the program TABLE4 produces desired details. The data files *LUN10. and *LUN25. produced during a simulation are normally available for five working days after the run and may be preserved (via the @SAVE command) for a longer period if desired (Section III-C).

Any of the four state variables, the number of days of feeding on old foliage or the number of days spent without food, are available through the use of the Table 4 program. Figure 8 gives the input codes that must be specified to retrieve this information.

To obtain any of these details, specify the total number of tree classes in the simulation, the number of items desired, and the (i,j)-code for each item. For example, if 24 tree classes had been used in a simulation and both the number of larvae starting the third instar and new foliage biomass at the end of feeding are of interest, then input the following:

1. 24 (tree classes)
2. 2 (number of items desired)
3. (4,3)
4. (8,1)

The format for these specifications and the necessary file assignments were given in previous sections.

Figure 8. The detailed information available in Table 4 and the specification codes to obtain it.

i: occasion code; this number is one greater than the access times of Figure 2.

j: variable code; the first four are the state variables.

i \ j	New foliage biomass	Old foliage biomass	Number of insects	Mean larval biomass1/	No. days on old foliage	No. days without food
Initiation of year	(1,1)	(1,2)	(1,3)	2/	2/	2/
Start first instar	(2,1)	(2,2)	(2,3)	(2,4)	2/	2/
Start second instar	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)5/	(3,6)5/
Start third instar	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)5/	(4,6)5/
Start fourth instar	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)5/	(5,6)5/
Start fifth instar	(6,1)	(6,2)	(6,3)	(6,4)	(6,5)5/	(6,6)5/
Start sixth instar	(7,1)	(7,2)	(7,3)	(7,4)	(7,5)5/	(7,6)5/
End larval stage, start pupal	(8,1)	(8,2)	(8,3)	(8,4)	(8,5)5/	(8,6)5/
Adult females to produce eggs	2/	2/	(9,3)	2/	2/	2/
Before over-winter mortality	(10,1)3/	(10,2)4/	(10,3)	2/	2/	2/

1/ Mean larval biomass follows a preassigned trajectory (according to initial biomass and growth rates) and changes only when the model branch is totally defoliated, i.e., item (i,6).

2/ The areas left blank indicate no usable information is available.

3/ New foliage (bud) potential for the following year's new foliage.

4/ Total foliage biomass before any shedding of old foliage.

5/ Number of days during the instar just completed.

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APPENDIX A

The parameters of *PARAMETERS. and their default values. The indices i and j refer to the record or card number (i) and the item (j) on that record.

i	j	Value	Description	Units
1	1	1	Beginning phase of the outbreak simulation	yr
1	2	**	No. of tree classes to be simulated	none
1	3	**	First tree class index of first subset	none
1	4	**	Last tree class index of first subset	none
1	5	--	First tree class index of second subset	none
1	6	--	Last tree class index of second subset	none
.				
.				
.				
1	21	--	First tree class index of the tenth subset	none
1	22	--	Last tree class index of the tenth subset	

**: Option of user but must be filled in

--: Option of user and can be omitted

Note: tree class indices must be less than 1000

i	j	Value	Description			Units
			Instar	Phase		
2	1	0.0	1			
2	2	0.0	2			
2	3	0.0	3	I		
2	4	0.0	4			
2	5	0.0	5			
2	6	0.0	6			
3	1	0.0	1			
3	2	0.0	2			
3	3	0.0	3	II	Instar-specific daily disease mortality rate	d^{-1}
3	4	0.0	4			
3	5	0.001	5			
3	6	0.001	6			
4	1	0.002	1			
4	2	0.003	2			
4	3	0.006	3	III		
4	4	0.013	4			
4	5	0.035	5			
4	6	0.028	6			
5	1	0.025	1			
5	2	0.028	2			
5	3	0.031	3	IV		
5	4	0.034	4			
5	5	0.035	5			
5	6	0.035	6			
6	1	0.0	1			
6	2	0.0	2			
6	3	0.0	3	I		
6	4	0.0	4			
6	5	0.0	5		Instar-specific daily predator/ parasite mortality rate	d^{-1}
6	6	0.0	6			
7	1	0.0	1			
7	2	0.0	2			
7	3	0.0	3	II		
7	4	0.0	4			
7	5	0.001	5			
7	6	0.001	6			

i	j	Value	Description			Units
			Instar	Phase		
8	1	0.001	1	III	Instar-specific daily predator/parasite mortality rate	d^{-1}
8	2	0.002	2			
8	3	0.003	3			
8	4	0.010	4			
8	5	0.016	5			
8	6	0.042	6			
9	1	0.005	1	IV		
9	2	0.006	2			
9	3	0.007	3			
9	4	0.021	4			
9	5	0.033	5			
9	6	0.056	6			
			Phase			
10	1	0.50	I		Natural pupal mortality rate	$occasion^{-1}$
10	2	0.62	II			
10	3	0.75	III			
10	4	0.80	IV			
10	5	200.0	I		Nominal Maximum egg-mass size; no. of eggs/mass	number
10	6	200.0	II			
11	1	150.0	III			
11	2	150.0	IV			
11	3	xx	blank field			none
11	4	0.50	I		Natural overwinter mortality rate	$occasion^{-1}$
11	5	0.60	II			
11	6	0.85	III			
12	1	0.90	IV			
12	2	0.0	Redistribution dispersal factor			
12	3	0.0	I		Establishment mortality rate	$occasion^{-1}$
12	4	0.0	II			
12	5	0.0	III			
12	6	0.0	IV			

xx: location is not used

i	j	Value	Description			Units
			Instar	Phase		
13	1	0.0	1			
13	2	0.0	2			
13	3	0.0	3	I		
13	4	0.0	4			
13	5	0.0	5			
13	6	0.0	6			
14	1	0.0	1			
14	2	0.0	2		Instar-specific daily control mortality rates	d^{-1}
14	3	0.0	3	II		
14	4	0.0	4			
14	5	0.0	5			
14	6	0.0	6			
15	1	0.0	1			
15	2	0.0	2			
15	3	0.0	3	III		
15	4	0.0	4			
15	5	0.0	5			
15	6	0.0	6			
16	1	0.0	1			
16	2	0.0	2			
16	3	0.0	3	IV		
16	4	0.0	4			
16	5	0.0	5			
16	6	0.0	6			
			Phase			
17	1	0.0	I			
17	2	0.0	II		Control pupal mortality rate	$occasion^{-1}$
17	3	0.0	III			
17	4	0.0	IV			
17	5	0.0	I			
17	6	0.0	II		Control overwinter mortality rate	$occasion^{-1}$
18	1	0.0	III			
18	2	0.0	IV			
18	3	xx				
18	4	xx				
18	5	xx				
18	6	xx				

i	j	Value	Description		Units
			Instar		
19	1	0.92	1	Instar-specific daily stress mortality rate for Douglas-fir	d^{-1}
19	2	0.60	2		
19	3	0.07	3		
19	4	0.0	4		
19	5	0.0	5		
19	6	0.0	6		
20	1	0.95	1	Instar-specific daily stress mortality rate for grand fir	d^{-1}
20	2	0.70	2		
20	3	0.10	3		
20	4	0.02	4		
20	5	0.0	5		
20	6	0.0	6		
21	1	0.02	1	Instar-specific daily background mortality rate	d^{-1}
21	2	0.02	2		
21	3	0.02	3		
21	4	0.02	4		
21	5	0.02	5		
21	6	0.02	6		
22	1	5.40	1	Instar-specific destruction/consumption ratio for new foliage	none
22	2	6.25	2		
22	3	6.25	3		
22	4	2.71	4		
22	5	2.27	5		
22	6	2.20	6		
23	1	5.40	1	Instar-specific destruction/consumption ratio for old foliage	none
23	2	6.25	2		
23	3	6.25	3		
23	4	3.69	4		
23	5	3.29	5		
23	6	3.20	6		

i	j	Value	Description	Units
24	1	1.19	Assimilated food to growth coefficient	none
24	2	0.081	Assimilated food to respiration coefficient	d^{-1}
24	3	0.10	Assimilation efficiency factor	none
24	4	0.1147	Instantaneous growth rate for the first three instars	d^{-1}
24	5	0.0886	Instantaneous growth rate for the fourth instar	d^{-1}
24	6	0.0625	Instantaneous growth rate for the last two instars	d^{-1}
25	1	0.197	Initial biomass of mean larvae at establishment	mg
25	2	52.063	Final biomass of mean female larvae at pupation if all food requirements have been met	mg
25	3	0.02	Coefficient of reduction in new foliage potential from the no. of days of total branch defoliation	d^{-1}
25	4	0.01	Coefficient of reduction in fecundity from no. of days of feeding on old foliage	d^{-1}
25	5	xx		
25	6	0.50	Proportion of larvae that are male (and pupate) at the end of the fifth instar	none

APPENDIX B
Sample Runstream

A "+" to the left of the line means that the line is not entered by you but is a response from the computer. The prompt ">" from the computer indicates that it is ready for a line of input.

```
  UBQ123
+ *UNIVAC 110 OPERATING SYSTEM  VER. 33-R3-3F    (RS1)*
  >RUN MØ1MAG,11Ø52Ø52Ø5  ,RUN1
+ DATE: Ø52179  TIME: 145456
+ THE SUBJECT FILE,  BROADCASTS, HAS BEEN UPDATED AS OF Ø5/21/79  11:21:21
+ READY
  >@QUAL RUN1
+ READY
  >@ADD,L DFTM*RUNSTREAM.PRE1

+ @DELETE,C *LUN25.
+ FURPUR 27R3A      E33 SL73R1 Ø5/21/79 14:55:55

+ *LUN25       IS NOT CATALOGUED OR ASSIGNED
+ FAC STATUS: 4ØØØ1ØØØØØØØ

+ @ASG,UP *LUN25.
+ READY

+ @USE 25,*LUN25
+ READY

+ @DELETE,C *LUN1Ø.
+ FURPUR 27R3A      E33 SL73R1 Ø5/21/79 14:56:1Ø

+ *LUN1Ø     IS NOT CATALOGUED OR ASSIGNED
+ FAC STATUS: 4ØØØ1ØØØØØØØ

+ @ASG,UP *LUN1Ø.
+ READY

+ @USE 1Ø,*LUN1Ø
+ READY

+ @ASG,T *1
+ READY

+ @ASG,T *2
+ READY

+ @ASG,T *3
+ READY
```

```
+ @ASG,T *4
+ READY

+ @ASG,T *5
+ READY

+ @ASG,T *6
+ READY

+ @ASG,T *7
+ READY

+ @ASG,T *8
+ READY

+ @ASG,T *9
+ READY

+ @ASG,T *11
+ READY

+ @ASG,T *12
+ READY

+ @ASG,UP *15
+ READY

+ @FREE *15
+ READY

+ @ASG,A *15
+ READY

+ @ASG,UP *16
+ READY

+ @FREE *16
+ READY

+ @ASG,A *16
+ READY

+ @ASG,UP *17
+ READY

+ @FREE *17
+ READY

+ @ASG,A *17
+ READY
```

```
+ @ASG,T *18
+ READY

+ @ASG,T *19
+ READY

+ @ASG,T *2Ø
+ READY

+ @ASG,UP *21
+ READY

+ @FREE *21
+ READY

+ @ASG,A *21
+ READY

+ @ASG,T *22
+ READY

+ @ASG,T *23
+ READY

+ @ASG,T *24
+ READY

+ @ASG,A DFTM*DFTMDF.
+ FACILITY WARNING  ØØØØØØØØ2ØØ

+ @USE 13,DFTM*DFTMDF
+ READY

+ @ASG,A DFTM*DFTMGF.
+ READY

+ @USE 14,DFTM*DFTMGF
+ READY

+ @ASG,A *IC.
+ READY

+ @ASG,A *PARAMETERS.
+ READY

+ @USE 3Ø,*IC
+ READY
```

```
+ @USE 6Ø,*PARAMETERS
+ READY
  >@XQT DFTM*OUTBREAK.NAME$
  >@ADD,L DFTM*RUNSTREAM.POST2

+ @FREE *2
+ READY

+ @FREE *3
+ READY

+ @FREE *4
+ READY

+ @FREE *5
+ READY

+ @FREE *6
+ READY

+ @FREE *7
+ READY

+ @FREE *8
+ READY

+ @FREE *9
+ READY

+ @FREE *1Ø
+ READY

+ @FREE *11
+ READY

+ @FREE *12
+ READY

+ @FREE *13
+ READY

+ @FREE *14
+ READY

+ @FREE *18
+ READY

+ @FREE *19
+ READY

+ @FREE *2Ø
+ READY
```

```
+ @FREE *21
+ READY

+ @FREE *22
+ READY

+ @FREE *23
+ READY

+ @FREE *24
+ READY

+ @FREE *25
+ READY
  >@SYM,U *15.,2,FCR1Ø4
  >@SYM,U *16.,2,FCR1Ø4
  >@SYM,U *17.,2,FCR1Ø4
  >@SYM,U *IC.,2,FCR1Ø4
  >@SYM,U *PARAMETERS.,2,FCR1Ø4
  >@FIN

    RUNID: MØ1MAG   ACCT: 11Ø52Ø52Ø5     PROJECT: RUN1
    TIME:     TOTAL: ØØ:Ø1:48.219
              CAU:   ØØ:ØØ:Ø5.563        I/O:  ØØ:ØØ:39.588
              CC/ER: ØØ:Ø1:Ø3.Ø68        WAIT: ØØ:Ø4:43.977

                 FCCC RESOURCE TIME :  ØØ:ØØ:42.944
    IMAGES  READ:   76         PAGES:  26
    START:    14:54:56 MAY 21, 1979   FIN:  15:Ø6:19 MAY 21,1979

  SIZE:  Ø12K

  EST COST:  TOTAL: ØØØ1Ø.17

             CPU:   ØØØØ2.22 I/O: ØØØØ7.2Ø  CONNECT: ØØØØ.75
  *TERMINAL INACTIVE*
  >@@TERM

  UBQ123
+ *UNIVAC 11ØØ OPERATING SYSTEM  VER. 33-R3-3F     (RSI)*
  >@RUN MØMAG,11Ø52Ø52Ø5  ,RUN1
+ DATE: Ø52179  TIME:  1753Ø4
+ THE SUBJECT FILE,  BROADCASTS, HAS BEEN UPDATED AS OF Ø5/21/79  14:55:5Ø
  >@QUAL RUN1
+ READY
  >@ADD,L DFTM*RUNSTREAM.TABLE4B

+ @ASG,A *SPECTAB4.
+ READY

+ @ASG,A *LUN1Ø.
+ READY
```

```
+ @ASG,A *LUN25.
+ READY

+ @DELETE,C *TABLE4.
+ FURPUR 27R3A      E33 SL73R1 Ø5/21/79 17:54:27

+ *TABLE4       IS NOT CATALOGUED OR ASSIGNED
+ FAC STATUS: 4ØØØ1ØØØØØØØ

+ @ASG,CP *TABLE4.
+ READY

+ @USE 11,*TABLE4
+ READY

+ @USE 12,*SPECTAB4
+ READY

+ @USE 1Ø,*LUN1Ø
+ READY

+ @USE 25,*LUN25
+ READY

+ @XQT DFTM*NTABLE4.A2
+ THERE WERE  15 TREE CLASSES COUNTED IN *LUN1Ø
+ REQUEST IS TO PROCESS THE FIRST  15 TREE CLASSES
+ THERE WERE  47 VALID ITEMS REQUESTED

+ @FREE 11
+ READY

+ @FREE *TABLE4.
+ FACILITY WARNING  1ØØØØØØØØØØØ

+ @FREE 12
+ READY

+ @FREE 1Ø
+ READY

+ @FREE25
+ READY
  >@SYM,U *TABLE4.,2,FCR1Ø4
  >@SYM,U *SPECTAB4.,2,FCR1Ø4
  >@FIN
```

```
  RUNID: MØ1MAG   ACCT:  11Ø52Ø52Ø5     PROJECT: RUN1
  TIME:    TOTAL: ØØ:Ø1:14.Ø55
         CAU:   ØØ:ØØ:Ø2.763       I/O:  ØØ:ØØ:51.947
         CC/ER: ØØ:ØØ:19.344       WAIT: ØØ:Ø3:17.562

            FCCC RESOURCE TIME :   ØØ:ØØ:25.423
  IMAGES  READ:   21        PAGES:   12
  START:    17:53:Ø4 MAY 21,1979     FIN:  17:58:45 MAY 21,1979

SIZE: Ø11K

EST COST:  TOTAL: ØØØ1Ø.84

        CPU:   ØØØØ1.11 I/O: ØØØØ9.36 CONNECT: ØØØØ.37
*TERMINAL INACTIVE*
>@@TERM
```

APPENDIX C

<u>Other model parameters</u>. Several model parameters in the file *PARAMETERS. already have been discussed. Twenty-eight other model parameters have not been addressed; for the most part, these are parameters you will not be interested in manipulating. You should know, however, what their effects are on the model and simulation output.

Four parameters are related to overwinter mortality. These are the establishment mortality rates. At present, knowledge of changes in insect density between fall oviposition and spring establishment of larvae is insufficient to quantify separately overwinter reduction and spring establishment loss. The total is incorporated as one overwinter parameter. This overwinter mortality accounts for all mortality between oviposition and establishment of the feeding population the following summer.

Redistribution of insects between tree classes is obtained by changing the redistribution dispersal factor from its default value of zero. This factor indicates what proportion of the variance in insect density between tree classes should be removed each year. When given the value 0.25, the variation between tree classes (weighted by number of trees and crown weight per tree) will be reduced by 25 percent for each year simulated. A range of 0.20 to 0.30 was found to give reasonable behavior when compared with a limited data set (four stands examined). With stand inventory and insect sample data sufficient to utilize this model feature, 0.25 is the suggested value.

As larvae develop, a series of food assimilation parameters are used as well as the destruction/consumption ratios and growth rates given in Appendix A. The derivation of the assimilation parameters is given in Overton <u>et al.</u> (1978). Destruction/consumption ratios are derived from Beckwith (1978) and growth rate data are from Mason (personal communication). The growth rates are instantaneous daily rates. They are used to determine the change in average individual larval biomass (dry weight). The population is assumed to consume foliage according to the number of insects, the size of the average insect, and the daily growth rate:

$$\text{Consumption}_t = N_t \ Wt_t(e^{k_t(1)} - 1) \ A$$

where

N_t : number of insects feeding on day t,

Wt_t : dry weight of the average insect to begin t,

$(e^{k_t(1)} - 1)$: growth increment (dry wt.) proportion to be accumulated on one day t from growth rate k_t,

A : assimilation factor for conversion of insect dry weight gain into foliage dry weight consumption,

Consumption_t: total dry weight consumed by the N_t insects in maintaining growth on day t.

The assimilation factor A =

$$\frac{1}{k_3}\left(k_1 + \frac{k_2}{k_t}\right)\left(\frac{1\ \text{g}}{10^3\ \text{mg}}\right)$$

Here:

k_1: assimilated food to growth coefficient (Appendix A; i=24, j=1),

k_2: assimilated food to respiration coefficient (Appendix A ; i=24, j=2)

k_3: assimilation efficiency (Appendix A; i=24, j=3)

k_t: instantaneous growth rate for day t.

Changes in the assimilation coefficients or growth rates should not be made without first reviewing the procedure by which these were derived (Overton et al. 1978). Also, changes in growth rates should not be made without also changing the initial or final mean larval biomass accordingly.

Consumption is transformed to foliage destroyed daily by use of the destruction/consumption ratio (Appendix A; i=22, 23). This ratio is instar- and foliage age- (new, old) specific but not host species specific.

Half the insects are assumed to be males and pupate at the end of the fifth instar (Appendix A; i=25, j=6). Assuming that male and female pupae are subject to the same mortality factors, females will be subjected to further mortality in the additional instar--hence differences in adult sex ratio.

The remaining two parameters are coefficients for reducing the ability of the insect and host to reproduce. First, new foliage potential, the ability of a tree to flush buds set in the previous year, is reduced by two percent (Appendix A; i=25, j=3) for each day the larvae would be actively feeding past the time of total defoliation (of the model branch). This accounts for buds destroyed by larvae during this period as well as the buds killed indirectly by stress from early total defoliation. New foliage potential is also reduced as a result of defoliation when the model branch is only partially defoliated.

Second, nominal fecundity is reduced by one percent (Appendix A; i=25, j=4) for each day the population feeds on old foliage. This accounts for the indirect effects of food quality on larval development and consequent reduced egg-mass size.

APPENDIX D

The two host effects files, DFTM*DFTMDF. and DFTM*DFTMGF., are read in from logical units 13 and 14, respectively, using the following two formats: the first seven records use (8F6.3); the last two records use (6F6.3). Figure 9 shows the standard DFTM*DFTMDF. and DFTM*DFTMGF. files. For each host species, the effects of defoliation were determined by analysis of impact plot data to produce an array, A, of expectations of the various measurements taken as follows:

A(i,j) i-row: card or record number in the file.

j-column: entry number across a record.

For i=1,...,7 the following correspondences exist:

1: all parameters correspond to trees (a tree class) with less than 15 percent of the crown totally defoliated,

2: all parameters correspond to trees with between 15 and 35 percent of the crown totally defoliated,

3: parameters for trees with between 35 and 65 percent of the crown totally defoliated,

4: parameters for trees with between 65 and 85 percent of the crown totally defoliated,

5: parameters for trees with between 85 and 95 percent of the crown totally defoliated,

6: parameters for trees with between 95 and 99.5 percent of the crown totally defoliated,

7: parameters for trees with between 99.5 and 100 percent of the crown totally defoliated,

and for each of the above values of i, the following definitions of A(i,j) for j=1,...,8 exists:

1: expected proportion of trees for which mortality is directly attributable to defoliation,

2: expected proportion of trees with no top-kill damage,

3: expected proportion of trees with leader-kill, one year's growth only

4: expected proportion of trees with top-kill less than 10 percent,

5: expected proportion of trees with top-kill less than 25 percent,

Figure 9. (a) the standard DFTM*DFTMDF. file.

0.000	0.940	0.035	0.013	0.017	0.021	0.025	0.850
0.000	0.867	0.090	0.031	0.039	0.041	0.042	0.785
0.009	0.712	0.138	0.095	0.128	0.141	0.150	0.740
0.028	0.569	0.183	0.111	0.157	0.209	0.248	0.717
0.173	0.493	0.240	0.075	0.103	0.123	0.267	0.691
0.477	0.460	0.189	0.081	0.135	0.135	0.351	0.619
0.923	0.460	0.189	0.081	0.135	0.135	0.351	0.619
0.014	0.005	0.022	0.030	0.053	0.472		
0.029	0.021	0.032	0.000	0.000	0.143		

(b) the standard DFTM*DFTMGF. file.

0.000	0.879	0.073	0.048	0.048	0.048	0.048	0.892
0.000	0.762	0.143	0.072	0.072	0.072	0.095	0.801
0.009	0.555	0.191	0.222	0.222	0.254	0.254	0.754
0.028	0.457	0.257	0.171	0.171	0.286	0.286	0.727
0.173	0.475	0.175	0.075	0.075	0.200	0.350	0.698
0.477	0.462	0.308	0.076	0.076	0.076	0.230	0.572
0.923	0.462	0.308	0.076	0.076	0.076	0.230	0.572
0.068	0.000	0.034	0.333	0.250	0.667		
0.076	0.049	0.000	0.143	0.000	0.667		

6: expected proportion of trees with top-kill less than 50 percent,

7: expected proportion of trees with some top-kill,

8: expected loss in diameter growth from defoliation.

The last two records in these files contain the information necessary to remove secondary mortality from the arrays described above. They are as follows:

A(i,j): i=8: expectations of secondary mortality associated with bark beetle secondary attack,

9: expectations of secondary mortality from all other causes, e.g., windthrow, winterkill, natural attrition,

j=1: expectation for trees without top-kill,

2: expectation for trees with leader-kill only,

3: expectation for trees with more than leader-kill, but less than 10 percent top kill,

4: expectation for trees with top-kill between 10 and 25 percent,

5: expectation for trees with top-kill between 25 and 50 percent,

6: expectation for trees with top-kill greater than 50 percent.

Mortality and degree of top-kill and growth loss have been incorporated as the effects of varying ranges of defoliation. The model follows the population of insects through four years on the model branch and then translates model branch defoliation into percent crown totally defoliated. From this variable, one of the host-specific vectors of effects is obtained from the inputs given in DFTM*DFTMDF. or DFTM*DFTMGF. (Section II-B).

Direct mortality has been measured by tallying all trees dead the year after peak defoliation that show no signs of secondary beetle attacks. Any tree showing signs of beetle galleries was assumed to be killed by bark beetles. Trees were followed for an additional four years after tussock moth population collapse. All trees subsequently dying and containing beetle galleries at death were assumed killed by beetles. All other mortalities in these years were incorporated into the "other causes" category (Wickman 1977).

The two forms of secondary mortality are assumed to act independently, hence the two vectors are combined by the rule:

$$(m_{1,j} + m_{2,j} - m_{1,j}m_{2,j})_j = v_j.$$

The scalar- or dot-product of this vector with the input vector of residuals of direct mortality is then used to compute secondary mortality for each defoliation class:

$$\sum_{j=2}^{6} v_j r_{i,j+1} = s_i, \; i=1,\ldots,7.$$

Here $r_{i,j}$ is the vector of residuals (ith record of DFTM*DFTMGF. or DFTM*DFTMDF.) and s_i is the derived secondary mortality that will be used in Table 2 of simulation output.

After secondary mortality has been subtracted from the residuals of direct mortality, the remaining numbers are the expected proportions that are to receive various levels of top-kill, and one class that indicates the proportion receiving only growth reductions.

Growth reductions attributable to defoliation are changes in diameter growth at breast height and height growth. At present, only diameter growth has been sampled. Until further data become available, the reduction multiplier for normal diameter growth will be used for reducing height growth. These multipliers are measures of the proportion of nominal growth attained after the given range of defoliation.

The parameters in either of these files can be altered by the users to affect any measured or theorized changes in defoliation effects.